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FISH BOWL SERIES

ADDENDUM TO PROJECT OFFICER REPORT — PROJECT 6.2

GAMMA RAY SCANNING OF DEBRIS CLOUD (U)

W. W. Berning, Project Officer

Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

and

Staff Members of
Electro-Optical Systems, Inc.
Pasadena, California

[redacted]

Issuance Date: May 6, 1966

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USAEC Division of Technical Information Extension, Oak Ridge, Tennessee

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ABSTRACT

This report covers the data reduction phase of the project.

The work was concerned with the determination of the payload attitude of a number of high-altitude rocket flights. From this information the pointing direction of the various directional detectors aboard the rockets is available for analysis. The telemetry data, transmitted from the rockets, was prepared in a digital form on tape for input to a computer program. The computer program calculated the payload attitude in a Johnston Island coordinate system. The outputs of the detector functional values and detector orientation parameters, trajectory parameters, and associated telemetry data are available in printed form as a function of time in increments of 11 milliseconds.

The report discusses the theoretical basis for attitude determination of the payloads and presents the computer program in its final form as used in the data reduction. A description of the data reduction results is included as the last section and discusses the final form of the computer outputs and character of the data.

Binary coded digital data tapes were prepared during the computer processing of the data for use as input to a data analysis program currently in progress.

The results and analysis of the Project 6.2 Fish Bowl data will appear in the Final Report of Contract DA-49-146-XZ-201.

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CHAPTER 1

INTRODUCTION

This report covers the data reduction phase of Project 6.2, and is intended as an addendum to POR–2017 (Reference 1).

The work was performed under DASA Contract DA-49-146-XZ-123 (EOS in-house work authorization WA 2194). It was concerned with the determination of the payload attitude of a number of high-altitude rocket flights. From this information the pointing direction of the various directional detectors aboard the rockets is available for analysis. The telemetry data, transmitted from the rockets, was prepared in a digital form on tape for input to a computer program. The computer program calculated the payload attitude in a Johnston Island coordinate system. The outputs of the detector functional values and detector orientation parameters, trajectory parameters, and associated telemetry data are available in printed form as a function of time in increments of 11 milliseconds.

The report discusses the theoretical basis for attitude determination of the payloads and presents the computer program in its final form as used in the data reduction. A description of the data reduction results is included as the last section and discusses the final form of the computer outputs and character of the data.

Binary coded digital data tapes were prepared during the computer processing of the data for use as input to a data analysis program (Contract DA-49-146-XZ-201) currently in progress.

The presentation of the results and analysis of the Project 6.2 Fish Bowl data will appear in the Final Report of Contract DA-49-146-XZ-201.

CHAPTER 2

THEORETICAL DISCUSSION OF ATTITUDE DETERMINATION

2.1 DEFINITION OF PROBLEM

To adequately describe the debris cloud resulting from the nuclear explosion, it is essential to know the direction, at any time, of each detector on the payload relative to an inertial coordinate system. Since the payload flight time is small relative to the earth's period of rotation, the coordinate system can, for most practical purposes, be fixed in the earth without resulting in a significant error. Thus, during an interval of 400 seconds, which is the average flight time, the earth will rotate through an angle of 1.68 degrees. This error is probably less than the accuracy with which one can determine the payload attitude by means of the magnetometer data. A convenient coordinate system for determining the payload attitude is the x, y, z system shown in Figure 2.1(a) which has its origin at Johnston Island. The z-axis points along the local vertical (out of the earth), the y-axis points to true (geographic) north, and the x-axis points due east. Here, D denotes the sensitive axis of a detector (e.g., a gamma scanner) where θ and ϕ are the polar coordinates of this axis. Figure 2.1(b) defines the fixed polar angles θ', ϕ' of the detector axis relative to the x', y' and z' magnetometer axes. The values of θ', ϕ' for the four detectors in the payload are shown in Table 2.1. Although the origin of the x', y', and z' system moves through space with the payload, it can be considered to coincide with Johnston Island if only rotation between the x', y', z' and x, y, z systems is to be measured (Figure 2.1(c)).

Here, $\vec{A}$ and $\vec{f}$ are unit vectors pointing in the direction of the z' axis (the vehicle longitudinal axis) and the earth's magnetic field vector $\vec{F}$, respectively. The problem is to determine θ (t) and ϕ (t), given θ', ϕ', $\vec{A}$, $\vec{f}$ and the x', y' magnetometer readings.

The polar angles θ and ϕ are given by

$$\phi = \tan^{-1}\left[\cos(D,x)/\cos(D,y)\right] \tag{2.1}$$

$$\theta = \sin^{-1}\left[\cos(D,z)\right] \tag{2.2}$$

where:

$$\cos(D,x) = a_{11}\cos\theta'\sin\phi' + a_{21}\cos\theta'\cos\phi' + a_{31}\sin\theta'$$

$$\cos(D,y) = a_{12}\cos\theta'\sin\phi' + a_{22}\cos\theta'\cos\phi' + a_{32}\sin\theta'$$

$$\cos(D,z) = a_{13}\cos\theta'\sin\phi' + a_{23}\cos\theta'\cos\phi' + a_{33}\sin\theta'$$

Here, a_{ij} are the transformation (rotation) coefficients, i.e., direction cosines, between the x and x' systems. Thus,

$$\begin{aligned} x' &= a_{11}x + a_{12}y + a_{13}z \\ y' &= a_{21}x + a_{22}y + a_{23}z \\ z' &= a_{31}x + a_{32}y + a_{33}z \end{aligned} \tag{2.3}$$

The vector $\vec{A}$ is then given by

$$\vec{A} = \vec{i}\,a_{31} + \vec{j}\,a_{32} + \vec{k}\,a_{33} \tag{2.4}$$

where $\vec{i}$, $\vec{j}$, $\vec{k}$ are unit vectors along the positive x, y, z axes, respectively. Also,

$$\vec{f} = \frac{\vec{F}}{|\vec{F}|} = \vec{i}\cos(F,x) + \vec{j}\cos(F,y) + \vec{k}\cos(F,z) \tag{2.5}$$

where $\vec{f}$ is known. The determination of $\vec{A}$ is discussed below. The remaining six coefficients a_{11}, a_{12}, a_{13}, a_{21}, a_{22}, a_{23}, are determined from $\vec{A}$, $\vec{f}$ and the x', y' magnetometer readings, also discussed below.

2.2 DETERMINATION OF $\vec{A}$

2.2.1 General Discussion. Recall that $\vec{A}$ is a unit vector along the vehicle longitudinal axis, i.e., the vehicle spin axis. As the vehicle accelerates upward from the launch pad, the rush of air past the canted fins on the rear causes the vehicle to spin. As the vehicle gains in altitude and the velocity vector $\vec{V}$ begins to move toward the horizontal (due to the pull of gravity), the vehicle will tend to acquire an angle of attack, i.e., the velocity vector will no longer coincide with $\vec{A}$, but will lie slightly below it. If the vehicle were not spinning (fins not canted) it would feather into the wind like an arrow, i.e., $\vec{A}$ would rotate with the velocity vector, pointing in the direction of $\vec{V}$. Since the vehicle is spinning, the torque applied about the center of mass by the air drag (the drag force is parallel and opposite to $\vec{V}$ and is applied at the vehicle center of pressure , which does not coincide with the center of mass) will cause the vehicle to precess about $\vec{V}$, which is referred to as the coning motion. If the vehicle is low in the atmosphere and if $\vec{V}$ is rotating rapidly (a low-summit trajectory), the increasing torque will cause severe coning and will eventually cause the vehicle to spin out flat. This is what happened to Rocket 18. If the vehicle is climbing rapidly and the direction of $\vec{V}$ is changing slowly (a high-summit trajectory), the cone angle and coning frequency will remain practically constant, and the direction of the axis of the cone will remain fixed in space, coinciding with the direction of $\vec{V}$ at the instant the uniform coning motion is established. This is the type of coning experienced by Rockets 15, 19, and 26.

If the initial acceleration is large and the launch is almost vertical, the drag force, and hence the torque, will be almost nonexistent (due to low air density) when the velocity vector finally begins to rotate, and, consequently, the vehicle will not cone. The direction of $\vec{A}$ will remain fixed in space coinciding with the direction of $\vec{V}$ shortly after launch. Rockets 8 and 9 did not experience any perceptible coning motion.

Since $\vec{A}$ coincides with $\vec{V}$ from the time of launch to the time when the coning motion is established, or for a short time after launch in the case of Rockets 8 and 9, it is important to know $\vec{V}$ during the early part of flight in order to determine the direction of $\vec{A}$ for the entire flight. The computed trajectories (parabolic) for all rockets begin at the BRL point, which occurs at varying times after launch. (The coning motion in Rockets 15, 19, and 26 begins after the BRL point; refer to Table 2.2.) In order to determine $\vec{V}$ from the time of launch to the BRL point, it is necessary to reconstruct the trajectory between these two times. This can done by a cubic fit, since the direction of $\vec{V}$ is known at launch and at the BRL point. Let $\vec{v}$ be a unit vector along $\vec{V}$, i.e.,

$$\vec{v} = \frac{\vec{V}}{|\vec{V}|} = \vec{i}\, v_1 + \vec{j}\, v_2 + \vec{k}\, v_3 \tag{2.6}$$

Then, if β_o, ψ_o, and β_1, ψ_1 are the azimuth and elevation (refer to Figure 2.2) of $\vec{V}$ at launch and the BRL point, respectively, the direction cosines are given as a function of z (the vertical direction in the Johnston Island coordinate system) as follows:

$$\begin{aligned} v_1 &= s_1 (1 + s_1^2 + s_2^2)^{-1/2} \\ v_2 &= s_2 (1 + s_1^2 + s_2^2)^{-1/2} \\ v_3 &= (1 + s_1^2 + s_2^2)^{-1/2} \end{aligned} \tag{2.7}$$

where:

$$s_1 = b_1 + 2b_2 z + 3b_3 z^2$$

$$s_2 = c_1 + 2c_2 z + 3c_3 z^2$$

$$b_1 = \cot \psi_o \sin \beta_o$$

$$b_2 = \frac{3x_1 - (\cot \psi_1 \sin \beta_1 + 2 \cot \psi_o \sin \beta_o)z_1}{z_1^2}$$

$$b_3 = \frac{-2x_1 + (\cot \psi_1 \sin \beta_1 + \cot \psi_o \sin \beta_o)z_1}{z_1^3}$$

$$c_1 = \cot \psi_o \cot \beta_o$$

$$c_2 = \frac{3y_1 - (\cot \psi_1 \cos \beta_1 + 2 \cot \psi_o \cos \beta_o)z_1}{z_1^2}$$

$$c_3 = \frac{-2y_1 + (\cot \psi_1 \cos \beta_1 + \cot \psi_o \cos \beta_o) z_1}{z_1^3}$$

and x_1, y_1, z_1 are the coordinates of the BRL point in the x, y, z system.

2.2.2 Nonconing Motion. From amplified telemetry records of the z-magnetometer readings, it is possible to determine the times at which coning motion begins, for Rockets 15, 19, 26, and the times when relative motion between $\vec{A}$ and the earth's magnetic field $\vec{F}$ ceases (i.e., when $\vec{A}$ acquires a fixed direction in space), for Rockets 8 and 9. (Recall, the z-magnetometer lies along $\vec{A}$.) Since $\vec{F}$ remains practically constant (in magnitude and direction) over most of the flight, a nonvarying z-magnetometer reading is construed to mean a nonvarying $\vec{A}$. Table 2.2 shows the above times for the five rockets. All times are measured from launch. The last column shows the length of time that $\vec{A}$ coincides with $\vec{v}$, i.e., $a_{31} = v_1$, $a_{32} = v_2$, $a_{33} = v_3$. During the period from launch to the BRL time, v_1, v_2, v_3 are given by Equation 2.7. During the period from the BRL time to the time shown in the

last column, v_1, v_2, v_3 are given by the parabolic trajectory. For Rockets 8 and 9, $\vec{A}$ maintains (until reentry) the direction it acquired at the time shown in the last column.

2.2.3 Coning Motion of $\vec{A}$. The coning motion of Rockets 15, 19, 26 can be divided into two phases: coning buildup, and uniform coning. The times shown in the third column of Table 2.2 actually represent the beginning of the coning buildup phase. During this phase, the amplitude and period of the oscillatory z-magnetometer (amplified) readings increase from zero to their final constant values for uniform coning motion. In order to determine the vector $\vec{A}$, we then proceed as follows. Let $\vec{v}_o$ denote the unit vector which lies along the axis of the circular cone (in the direction of the velocity vector) which is described by $\vec{A}$ during the uniform coning phase. We write

$$\vec{v}_o = \vec{i}v_{10} + \vec{j}v_{20} + \vec{k}v_{30} \tag{2.8}$$

The method of computing the components of $\vec{v}_o$ is described later in this section. We now construct a set of orthogonal unit vectors $\vec{e}_1$, $\vec{e}_2$, $\vec{e}_3$ as follows:

$$\vec{e}_1 = \frac{\vec{f} - (\vec{v}_o \cdot \vec{f})\vec{v}_o}{[1 - (\vec{v}_o \cdot \vec{f})^2]^{1/2}}, \quad \vec{e}_3 = \vec{v}_o, \quad \vec{e}_2 = \vec{e}_3 \times \vec{e}_1 \tag{2.9}$$

Refer to Figure 2.3. Thus, $\vec{e}_1$ lies in the plane defined by $\vec{v}_o$ and $\vec{f}$. In Equation 2.9, $\vec{f}$ is given by Equation 2.5, and $\vec{v}_o$ by Equation 2.8. Now, for circular coning motion

$$\vec{A} = \sin\gamma\cos(\omega t-\delta_c)\vec{e}_1 + \sin\gamma\sin(\omega t-\delta_c)\vec{e}_2 + \cos\gamma\,\vec{e}_3 \quad \ldots.(2.10)$$

where, γ is the cone half-angle, ω is the coning frequency, and δ_c is the coning phase angle. Since $\vec{f}$ and $\vec{v}_o$ are expressed in terms of the Johnston Island coordinate system, therefore, $\vec{e}_1$, $\vec{e}_2$, $\vec{e}_3$ will also be expressed in this system. On substituting Equation 2.9 into Equation 2.10, $\vec{A}$

will be given in this system and, hence, the quantities $a_{31}(t)$, $a_{32}(t)$, $a_{33}(t)$ can be readily identified (refer to Equation 2.4). The mechanics of evaluating $\vec{e}_1$, $\vec{e}_2$, $\vec{e}_3$, substituting them in Equation 2.10 and identifying the $a_{3i}(t)$, can be programmed on the digital computer.

In order to determine a_{31}, a_{32}, a_{33}, we must know the quantities γ, ω, δ_c. These are discussed below.

Uniform Coning. The amplified telemetry records of the z-magnetometer readings for Rockets 15, 19, 26 verify that the vector $\vec{A}$ ultimately describes circular, coning motion. In order to make an accurate determination of the cone half-angle, γ, we proceed as follows: Figure 2.4 shows the extreme locations of the coning z' axis (z-magnetometer axis) which are coplanar with the earth's magnetic field vector $\vec{F}$, and the corresponding locations of the x' axis (x-magnetometer axis), coplanar with $\vec{F}$, z_1', z_2', which yield the maximum positive x-magnetometer readings, M_{x1} and M_{x2} (recall, x' rotates about z'). Figure 2.5 shows a general plot of the x-magnetometer reading as it appears on Rockets 15, 19, 26 during the uniform coning phase. From Figure 2.4

$$\cos(\pi/2 - \alpha_1) = M_{x1}/F = \sin \alpha_1$$
$$\cos(\pi/2 - \alpha_2) = M_{x2}/F = \sin \alpha_2$$

Hence,

$$2\gamma = \alpha_2 - \alpha_1 = \sin^{-1}(M_{x2}/F) - \sin^{-1}(M_{x1}/F)$$

where, F is the theoretical field. Although the above equation provides an accurate determination of γ, this equation cannot be employed, due to the fact that γ is too small ($< 8^{\circ}$) to permit an accurate and reliable distinction between M_{x1} and M_{x2}.

The relatively small coning angles experienced on Flights 15, 19, 26 permit, however, a simple and accurate computation of γ. From Figure 2.6(a), $\cos \alpha = M_z/F$. Differentiating gives

$$-\sin \alpha \cdot \Delta\alpha = \Delta M_z/F$$

where ΔM_z is defined in Figure 2.6(b), which shows a time plot of the z-magnetometer reading, M_z. Since the coning angle is small, the differential $\Delta\alpha$ can be written, $\Delta\alpha = 2\gamma$. If x', Figure 2.6(a), is coplanar with z' and $\vec{F}$, then the x-magnetometer will read a maximum positive value, M_{xmax}. Hence,

$$\cos(\pi/2 - \alpha) = M_{xmax}/F = \sin\alpha$$

Eliminating $\sin\alpha$ from the above two equations and disregarding the minus sign, we get

$$\Delta\alpha = 2\gamma = \Delta M_z/M_{xmax} \tag{2.11}$$

This equation has the advantage of not containing the magnetic field strength F.

The coning frequency, ω, is obtained simply by

$$\omega = 2\pi/T \tag{2.12}$$

where, T = period of uniform coning.

Since $\vec{f}$ (Figure 2.3) lies in the plane of $\vec{v}_o$ and $\vec{e}_1$, the angle between $\vec{A}$ and $\vec{f}$ will be a minimum when the $\vec{e}_1$ component of $\vec{A}$ is a maximum. However, when this angle is a minimum, the z-magnetometer reading will be a maximum. Let t' be the time when a maximum z-magnetometer reading occurs during the uniform coning phase. Then the $\vec{e}_1$ component of $\vec{A}$ will be maximum (Equation 2.10) when $\omega t' - \delta_c = 0$, or

$$\delta_c = \omega t' \tag{2.13}$$

In passing, we point out that, if the angular momentum vector of coning points in the direction of $\vec{v}_o$, then $\omega > 0$. If it points in the opposite direction, then $\omega < 0$. The vehicle cones in the same direction that it spins.

Coning Buildup. If we replace the angle $\omega t - \delta_c$ with the symbol, χ, then Equation 2.10 becomes

$$A = \sin\gamma \cos\chi \, \vec{e}_1 + \sin\gamma \sin\chi \, \vec{e}_2 + \cos\gamma \, \vec{e}_3 \tag{2.14}$$

where χ is defined in Figure 2.7. During the coning buildup phase, the angle χ is not a linear function of time, due to the fact that the coning frequency ω is not a constant. A satisfactory description of χ during the buildup phase is obtained as follows. From Figure 2.7 we see that the z-magnetometer reading will be a maximum when $\vec{A}$ lies in the $\vec{e}_1$, $\vec{v}_o$ plane between $\vec{e}_1$ and $\vec{v}_o$, i.e., when $\chi = 0$, and that it will be a minimum when $\vec{A}$ lies in this same plane outside of $\vec{e}_1$ and $\vec{v}_o$, i.e., when $\chi = \pi$. Since the times at which the extreme values of M_z occur are known, it is possible to make a graph of χ versus t according to the following rule:

$$\chi = 2n\pi \ (n = 0, 1, 2....), \text{ for maximum } M_z$$

$$\chi = (2n+1)\pi \ (n = 0, 1, 2....), \text{ for minimum } M_z \tag{2.15}$$

During coning buildup, the angle γ increases from zero to its final, constant value for uniform coning. In order to determine the behavior of γ during coning buildup, we proceed as follows. From Figure 2.7 we see that

$$\vec{f} = \sin\lambda\ \vec{e}_1 + \cos\lambda\ \vec{e}_3 \tag{2.16}$$

Since $\vec{f} \cdot \vec{A} = M_z/F$, where, F = magnetic field strength, therefore, from Equations 2.13 and 2.16, we get

$$M_z/F = \sin\lambda \sin\gamma \cos\chi + \cos\lambda \cos\gamma$$

Employing Equation 2.15 we then get

$$M_{zmax} = F(\sin\lambda \sin\gamma + \cos\lambda \cos\gamma)$$

$$M_{zmin} = F(-\sin\lambda \sin\gamma + \cos\lambda \cos\gamma)$$

From the above two expressions we readily get

$$\gamma = \tan^{-1}\left(\frac{\cot\lambda}{\frac{2}{\eta} - 1}\right) \tag{2.17}$$

where,

$$\eta = \frac{M_{zmax} - M_{zmin}}{M_{zmax}} \quad (\eta \lesseqgtr 0)$$

Before Equation 2.17 can be employed to determine γ, we must first evaluate λ. During the uniform coning phase, we select any consecutive values of M_{zmax} and M_{zmin} and evaluate η. We then calculate the value of γ for the uniform coning phase, which is obtained from Equation 2.11, and substitute γ and η in Equation 2.17 and thereby determine λ. Thus,

$$\lambda = \cot^{-1}\left[\left(\frac{2}{\eta} - 1\right)\tan\left(\frac{\eta}{2}\frac{M_{zmax}}{M_{xmax}}\right)\right] \qquad (2.18)$$

Note that, $0 < \lambda < \pi$. Also, M_{zmax} may be positive or negative, but $M_{xmax} > 0$.

Having evaluated λ, we can now determine $\gamma(t)$ from Equation 2.17. Thus, we select consecutive values M_{zmax}, M_{zmin} (or, M_{zmin}, M_{zmax}) in the coning buildup phase, evaluate η, and then compute γ. The computed value of γ corresponds to the instant of time midway between M_{zmax} and M_{zmin}. By employing all the M_{zmax} and M_{zmin} readings in the buildup phase, we can therefore determine $\gamma(t)$ throughout this phase.

It is important to note that the λ appearing in Equation 2.17 remains unchanged during the computation of $\gamma(t)$, i.e., it is the single value computed from Equation 2.18.

Determination of $\vec{v}_o$. The components of $\vec{v}_o$ are the final quantities which must be evaluated before $\vec{A}$ can be determined from Equations 2.9 and 2.10. In Figure 2.8 $\vec{v}_o$ and $\vec{f}$ are defined by polar coordinates in the Johnston Island coordinate system. From Equation 2.8 and Figure 2.8 we see that

$$\begin{aligned} v_{10} &= \sin\mu_1 \sin\delta_1 \\ v_{20} &= \sin\mu_1 \cos\delta_1 \\ v_{30} &= \cos\mu_1 \end{aligned} \qquad (2.19)$$

The angle δ_1 is nothing more than the azimuth of the BRL parabolic trajectory, which is known. We must then determine μ_1. Since, $\vec{f} \cdot \vec{v}_o = \cos\lambda = v_{10}\sin\mu_2 \sin\delta_2 + v_{20}\sin\mu_2\cos\delta_2 + v_{30}\cos\mu_2$, we therefore have

$$\sin\mu_1 \sin\mu_2 \cos(\delta_2-\delta_1) + \cos\mu_1 \cos\mu_2 = \cos\lambda \qquad (2.20)$$

The λ appearing in Equation 2.20 is that computed from Equation 2.18. At Johnston Island, $\mu_2 = 119.85°$, $\delta_2 = 10.53°$. We may then solve Equation 2.20, by graphical means, for the unknown, μ_1.

Coning Characteristics of Rockets 15, 19, 26. Table 2.3 shows the salient coning characteristics of Rockets 15, 19, 26. These include the duration of the coning buildup phase, the angle λ between the cone axis $\vec{v}_o$ and the earth's magnetic field, $\vec{f}$, the polar coordinates (μ_1, δ_1) of $\vec{v}_o$, the cone half-angle γ, and the coning period, $T(= 2\pi/\omega)$. In the case of Rockets 8 and 9, $\vec{v}_o$ denotes the fixed direction in space assumed by the vehicle longitudinal axis, $\vec{A}$. This direction is simply that of the vehicle velocity vector at 110 seconds after launch. Also shown in Table 2.3 is the approximate frequency of spin of each rocket about its longitudinal axis, which was determined from the x-magnetometer data.

The rather unorthodox value of μ_1 computed for Rocket 19 is due to the questionable value of δ_1 employed in the calculation. Refer to Section 3.2 for a discussion of the azimuth of the Rocket 19 trajectory.

Figures 2.9 through 2.11 show $\gamma(t)$ and $\chi(t)$ during the coning buildup phase, for Rockets 15, 19, 26. Note that the slope of $\chi(t)$ becomes constant toward the end of the buildup period, indicating that $d\chi/dt = \omega =$ constant.

2.3 DETERMINATION OF a_{11}, a_{12}, a_{13}, a_{21}, a_{22}, AND a_{23}

2.3.1 General Discussion. The following method for computing the remaining six coefficients a_{11}, a_{12}, a_{13}, a_{21}, a_{22}, a_{23} applies equally to the coning buildup and uniform coning phases. Let $\vec{i}'$ and $\vec{j}'$ be unit vectors along the x', y' axes, respectively, i.e., along the sensitive axes of the x and y magnetometers (Figure 2.1). Thus

$$\begin{aligned} \vec{i}' &= a_{11}\vec{i} + a_{12}\vec{j} + a_{13}\vec{k} \\ \vec{j}' &= a_{21}\vec{i} + a_{22}\vec{j} + a_{23}\vec{k} \end{aligned} \tag{2.21}$$

Then, the unit vectors $\vec{i}'$, $\vec{j}'$, $\vec{A}$ form an orthogonal set (recall, $\vec{A}$ lies along the z-magnetometer axis). We now construct a set of orthogonal unit vectors $\vec{u}_1$, $\vec{u}_2$, $\vec{u}_3$ as follows (Figure 2.12):

$$\vec{u}_1 = \vec{A}, \quad \vec{u}_2 = \frac{\vec{f}-(\vec{A}\cdot\vec{f})\vec{A}}{[1-(\vec{A}\cdot\vec{f})^2]^{1/2}}, \quad \vec{u}_3 = \vec{u}_1 \times \vec{u}_2 \tag{2.22}$$

During coning buildup, $\vec{A}$ is given by Equation 2.14, and during uniform coning, it is given by Equation 2.10. From Figure 2.4 we see that

$$\begin{aligned} \vec{i}' &= \cos\sigma\, \vec{u}_2 - \sin\sigma\, \vec{u}_3 \\ \vec{j}' &= \sin\sigma\, \vec{u}_2 + \cos\sigma\, \vec{u}_3 \end{aligned} \tag{2.23}$$

where:

$$\cos\sigma = \frac{M_x}{(M_x^2 + M_y^2)^{1/2}}, \quad \sin\sigma = \frac{M_y}{(M_x^2 + M_y^2)^{1/2}} \tag{2.24}$$

Here, M_x and M_y are the x and y magnetometer readings, respectively. Since $\vec{A}$ and $\vec{f}$ are expressed in the Johnston Island system, therefore $\vec{u}_1$, $\vec{u}_2$, $\vec{u}_3$ will be expressed in this system and, consequently, so will $\vec{i}'$ and $\vec{j}'$. By comparing Equations 2.23 and 2.21 it should then be possible to identify the a_{11}, a_{12}, a_{13}, a_{21}, a_{22}, a_{23}. The mechanics of evaluating $\vec{u}_1$, $\vec{u}_2$, $\vec{u}_3$, $\vec{i}'$, $\vec{j}'$ and identifying the a_{ij} can be programmed on the digital computer.

<u>2.3.2 Rocket 19</u>. Of the flights being considered in this study, Rocket 19 is unique in that it was the only rocket actually in flight when burst occurred. One consequence of the burst was that the earth's local magnetic field experienced a temporary distortion, which lasted for approximately 100 seconds. During this time, the x,y,z magnetometer readings suffered a corresponding perturbation, thereby making them unsuitable for the purpose of attitude determination. It became necessary then to artificially simulate unperturbed magnetometer readings M_x, M_y, M_z in order that the rocket attitude could be successfully determined. Thus, the newly generated M_x and M_y would be substituted in Equation 2.24, and the simulated M_z would be employed to ascertain the cone half-angle, γ, during uniform coning. The natural M_z could be employed in Equations 2.17 and 2.18, since the burst occurred <u>after</u> the start of the uniform coning phase.

The task of generating M_x, M_y, M_z is simplified by the fact that the earth's (unperturbed) magnetic field changes by a negligible amount over that part of the trajectory in which the perturbation occurs. Thus, the earth's field can be regarded as a constant. The method of generating M_x, M_y, M_z is as follows. In Figure 2.13, the unit vectors $\vec{p}_1$, $\vec{p}_2$, $\vec{p}_3$ form a right-handed, orthogonal system where

$$\begin{aligned}\vec{p}_1 &= \cos(\chi + \pi/2)\,\vec{e}_1 + \sin(\chi + \pi/2)\,\vec{e}_2 \\ \vec{p}_2 &= \vec{A} \times \vec{p}_1 \\ \vec{p}_3 &= \vec{A}\end{aligned} \qquad (2.25)$$

Here, $\chi = \omega t - \delta_c$, and $\vec{A}$ is given by Equation 2.10, where ω = constant. From Figure 2.13 we see that

$$\vec{i}' = \cos\zeta\ \vec{p}_1 + \sin\zeta\ \vec{p}_2$$
$$\vec{j}' = -\sin\zeta\ \vec{p}_1 + \cos\zeta\ \vec{p}_2 \tag{2.26}$$

Since the angles $\chi + \pi/2$, γ, ζ are the usual Euler angles, therefore, $d\zeta/dt = \Omega - d(\chi + \pi/2)/dt + \cos\gamma$, or $\dot{\zeta} = \Omega - \omega \cos\gamma$, where Ω = frequency of spin of the vehicle about the $\vec{A}$ axis. Hence,

$$\zeta = (\Omega - \omega \cos\gamma)t - \delta_s \tag{2.27}$$

where, δ_s = spin phase angle. The field components along the magnetometer axes are given by

$$M_x = F_T(\vec{f} \cdot \vec{i}'),\ M_y = F_T(\vec{f} \cdot \vec{j}'),\ M_z = F_T(\vec{f} \cdot \vec{A}) \tag{2.28}$$

where, F_T is the magnitude of the earth's theoretical magnetic field, and $\vec{f}$ is given by Equation 2.16. Actually, the quantity F_T is not needed, since it cancels out when M_x and M_y are substituted in Equation 2.24. Also, in Equations 2.17 and 2.18, M_z occurs as a ratio, therefore making the use of F_T unnecessary.

In order to determine the spin phase angle δ_s, a value first must be assigned to the quantity $\Omega - \omega \cos\gamma$, which is the rate of change of the angle ζ in Figure 2.13. Although γ and ω can be determined from the unperturbed x and z magnetometer data (recall, the burst occurs after the start of uniform coning), there is no direct way to evaluate Ω, the spin frequency of the vehicle about its longitudinal axis. The frequency of the oscillating x or y magnetometer readings is not equal to Ω, due to the presence of coning, nor is it equal to $\Omega - \omega \cos\gamma$, since the frequency $\Omega - \omega \cos\gamma$ represents the angular rate between the $\vec{i}'$ direction (x magnetometer) and the moving line of nodes, $\vec{p}_1$ (Figure 2.13), whereas the frequency of the x magnetometer represents the angular rate between $\vec{i}'$ and the fixed direction $\vec{f}$. It is possible, however, to evaluate $\Omega - \omega \cos\gamma$ by making use of Equation 2.28. In doing so, though, we assume

that the vehicle indeed describes uniform coning motion and that the actual x, y and z magnetometer readings are accurately described by Equation 2.28.

Let t' be the time, during uniform coning (just prior to burst), when a maximum z magnetometer reading occurs. Then, making use of Equation 2.13, M_x and M_y in Equation 2.28 provide us with the following relation:

$$\delta_s = (\Omega - \omega \cos\gamma)t' - \tan^{-1}\left(\frac{M_x}{M_y}\right)_{t'} \tag{2.29}$$

Let t'' be the time (during uniform coning) when the x magnetometer reading passes through zero. Then, Equation 2.29 and the equation, $0 = \vec{f} \cdot \vec{i}'$, combine to yield the relation

$$\Omega - \omega \cos\gamma = \frac{1}{t''-t'}\left[\tan^{-1}\frac{\sin\omega(t''-t')}{\cot\lambda \sin\gamma - \cos\gamma \cos\omega(t''-t')} - \tan^{-1}\left(\frac{M_x}{M_y}\right)_{t'} \pm (n-1)\pi\right] \tag{2.30}$$

Here, the integer n (= 1,2,3----) denotes the number of zero crossings of M_x, following t', at which t'' is taken. Thus, if t'' occurs at the first zero crossing of M_x following t', then $n = 1$. The appropriate sign is chosen so as to make $\Omega - \omega \cos\gamma > 0$.

If the coning motion were indeed uniform, and the spin frequency of the vehicle about its longitudinal axis were constant, then we would expect the quantity $\Omega - \omega \cos\gamma$ to be a constant, independent of the choice of t' or t''. Unfortunately, however, this is not the case. Table 2.4 shows the computed values of $\Omega-\omega \cos\gamma$, from Equation 2.30, for five values of t''. In all cases, $t' = 107.6121$ sec ($t = 0$ corresponds to launch).

From the above nonuniformity of $\Omega - \omega \cos\gamma$, we must conclude that, either the coning motion, just prior to burst, is not actually uniform and that Ω is not constant, or that it is impossible to accurately locate the times t' and t'' from the digital printouts of the x and y magnetometer data.

It is possible to make an independent evaluation of ν ($= \Omega - \omega \cos\gamma$) by means of the data from the vertical gamma scanner detector. If both the vehicle and source of gamma rays (burst) were stationary in space, then the frequency f_γ of the gamma scanner data would equal the frequency f_a of the computed azimuth angle φ (Figure 2.1(a) and Equation 2.1) of the gamma scanner ($f_a = d\varphi/dt$). Since the vehicle is in motion, the quantity $f_\gamma - f_a$ will no longer be zero, but will vary from point to point along the trajectory. It is possible to precompute the value of $f_\gamma - f_a$ at any point on the trajectory, since the azimuth of the trajectory and the coordinates of the burst are known. Thus, we could compute $f_\gamma - f_a$ at some specified time, τ, and then employ that value of ν which produces the appropriate machine-computed value of f_a at time τ, i.e., the f_a which makes $f_\gamma - f_a$ equal to the precomputed value. We would then regard this value of ν as the correct one.

Unfortunately, it is not possible to employ the above scheme for determining ν, since the azimuth of the Rocket 19 trajectory is not well known (Reference 1, page 232).

As a consequence of this uncertainty in the trajectory, it was decided not to conduct any data reduction on Rocket 19 at this time. Presumably, if a more reliable estimate of the trajectory azimuth could be obtained, it would be possible to complete the analysis of this particular flight. This problem is presently being pursued under the 3850 data analysis program, since the determination of the parameters which may indicate the proper trajectory lies in an analysis of the Rocket 19 data.

2.4 ROCKET 18

Recall that the ultimate purpose of this study is to describe the shape, size, and nature of the debris cloud on the basis of data taken from the photometer, β-detector, and the four gamma scanners. This will be done by comparing the observed data from these six detectors with the computed (as a function of time) attitude of the detector axes. This task will be relatively simple in the case of Rockets 8, 9, 15, and 26, since these payloads are spinning at a reasonably constant rate. However, in the case of Rocket 18, the task would be formidable, since the spin rate of this rocket is extremely erratic, as evidenced by the x and y magnetometer readings. According to the telemetry records, the payload does not exhibit a well-defined spin, but instead appears to rotate aimlessly about the longitudinal axis (the longitudinal axis, however, describes a uniform 90-degree coning motion). Due to the irregular behavior of the spin frequency, it was decided not to perform a data reduction study on Rocket 18.

2.5 ROCKET 29

Attitude determination was not performed on this rocket, due to the fact that data were low level and unreliable.

TABLE 2.1 POINTING DIRECTION OF DETECTOR AXES

Detector	θ'	ϕ'
Photometer	0	90°
β-detector	0	90°
Horizontal gamma scanner	-15°	45°
Vertical gamma scanner	0	0

TABLE 2.2 TIME PARAMETERS FOR CONING

Rocket	BRL Time	Beginning of Coning	When $\vec{A}$ assumes a fixed direction	$\vec{A} = \vec{v}$, from launch until - - -
	sec	sec	sec	sec
8	110	----	110	110
9	110	----	110	110
15	40	45.6	---	45.6
19	30	48.6	---	48.6
26	35	31.0	---	31.0

TABLE 2.3 CONING CHARACTERISTICS

Rocket	Duration of Coning Buildup	λ	$\vec{v}_o$		Uniform Coning		Spin Frequency (cps)
			μ_1	δ_1	γ	T	
8	---	---	$30^o27'$	$26^o12'$	---	---	6.10
9	---	---	$21^o39'$	$23^o30'$	---	---	6.55
15	69.37 sec	$93^o40'$	$26^o36'$	21^o	$6^o35'$	25.75 sec	1.52
19	52.29 sec	$113^o52'$	-10^o	$135^o(?)$	$7^o56'$	25.70 sec	2.05
26	77.75 sec	$121^o\ 4'$	$6^o17'$	$113^o30'$	$1^o31'$	22.00 sec	2.44

TABLE 2.4 $\Omega - \omega$ COSγ FOR SEVERAL VALUES OF t''

$t''-t'$	$\Omega - \omega \cos\gamma$
- 0.1076 sec	12.42611 rad/sec
+ 0.1379 sec	12.67248 rad/sec
+ 0.3809 sec	12.68755 rad/sec
+ 0.6259 sec	12.64988 rad/sec
++ 5.7526 sec	12.56068 rad/sec

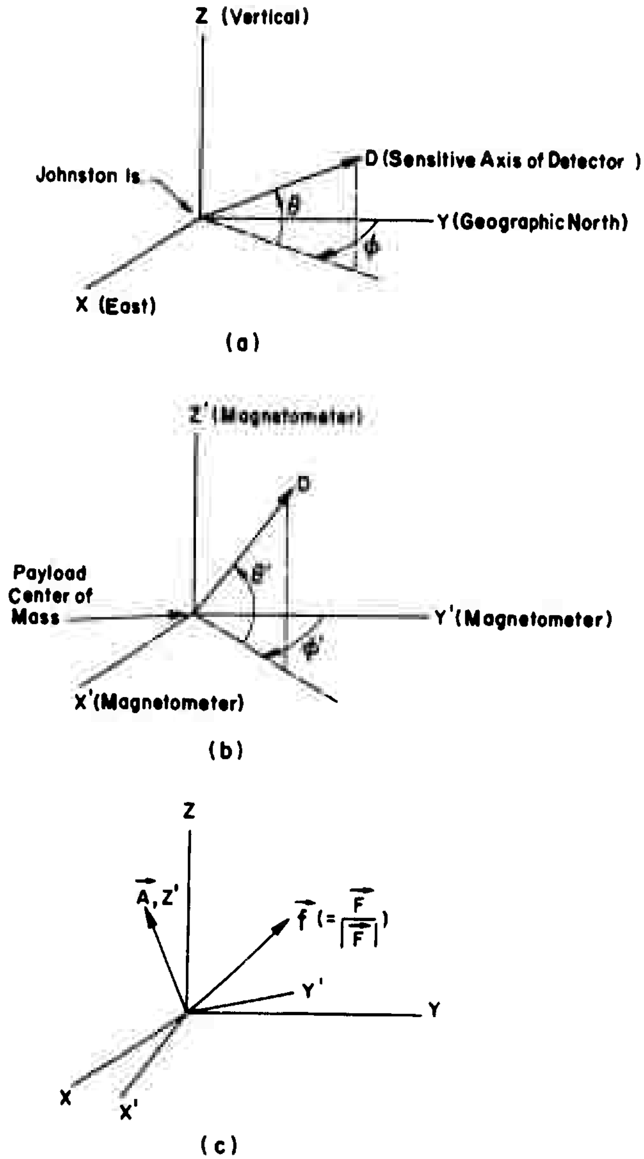


Figure 2.1 Definition of Johnston Island and payload coordinate systems.

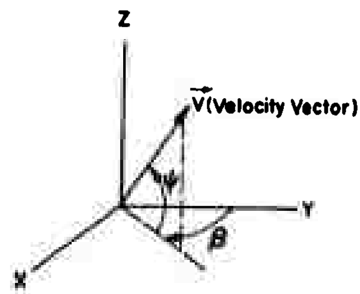


Figure 2.2 Definition of ψ and β.

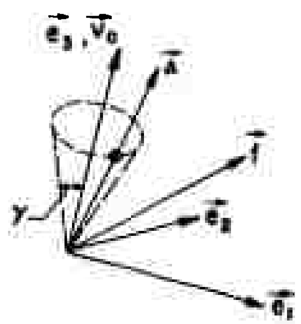


Figure 2.3 Definition of $\vec{e}_1$, $\vec{e}_2$, and $\vec{e}_3$.

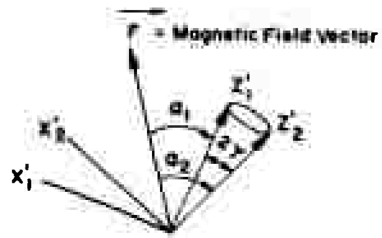


Figure 2.4 Derivation of γ.

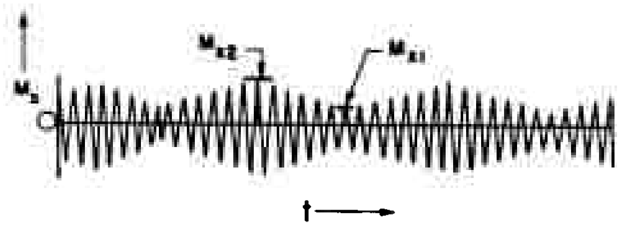
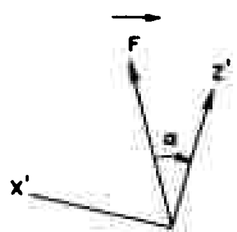
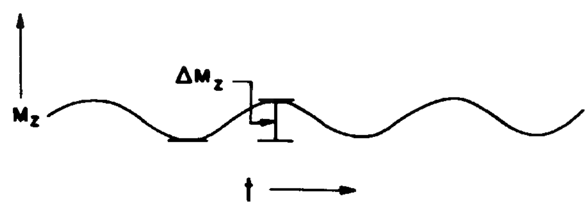


Figure 2.5 The x-magnetometer reading versus time.



(a)



(b)

Figure 2.6 Derivation of γ and definition of ΔM_Z.

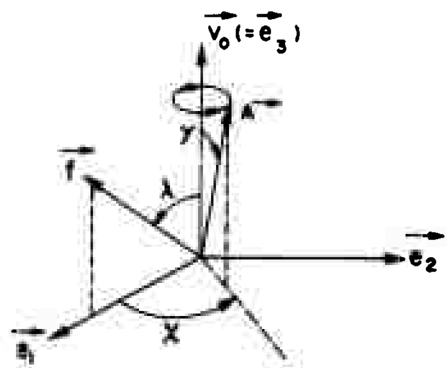


Figure 2.7 Definition of λ and χ.

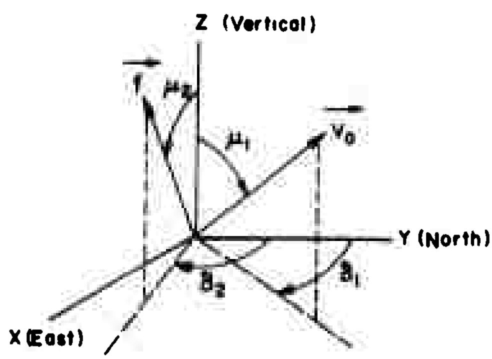


Figure 2.8 Definition of μ_1, μ_2, δ_1, and δ_2.

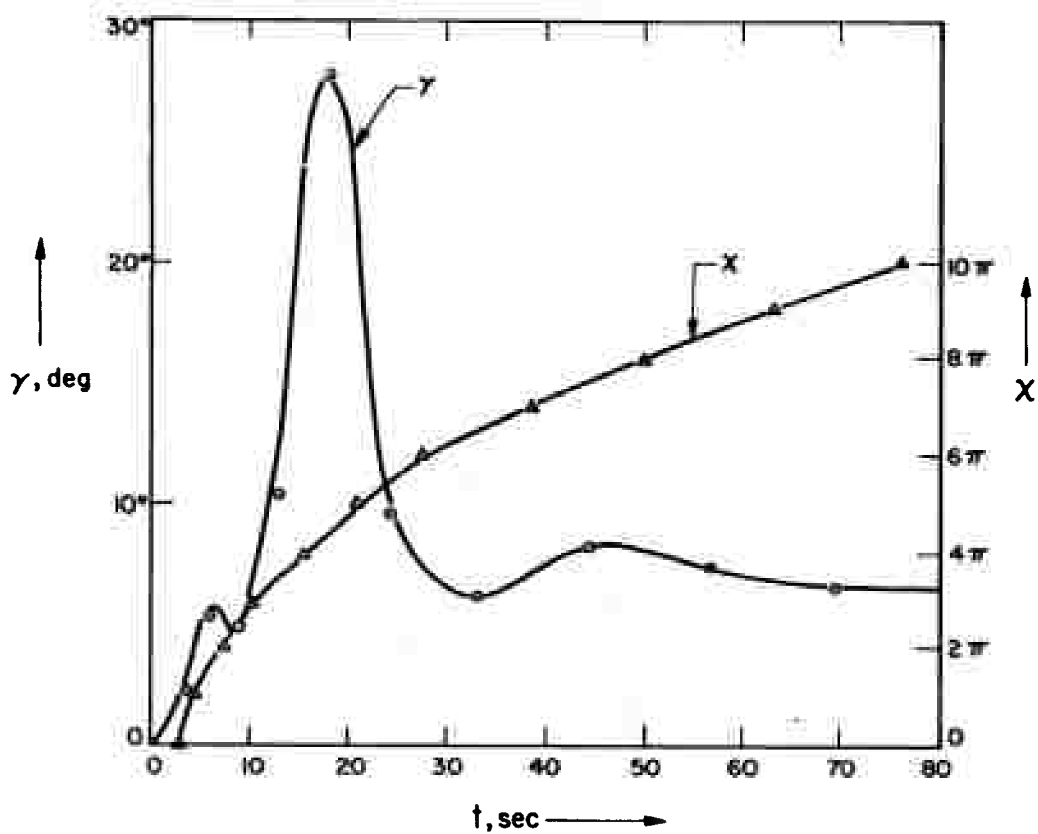


Figure 2.9 Cone half-angle γ and coning azimuthal angle χ versus time, Rocket 15.

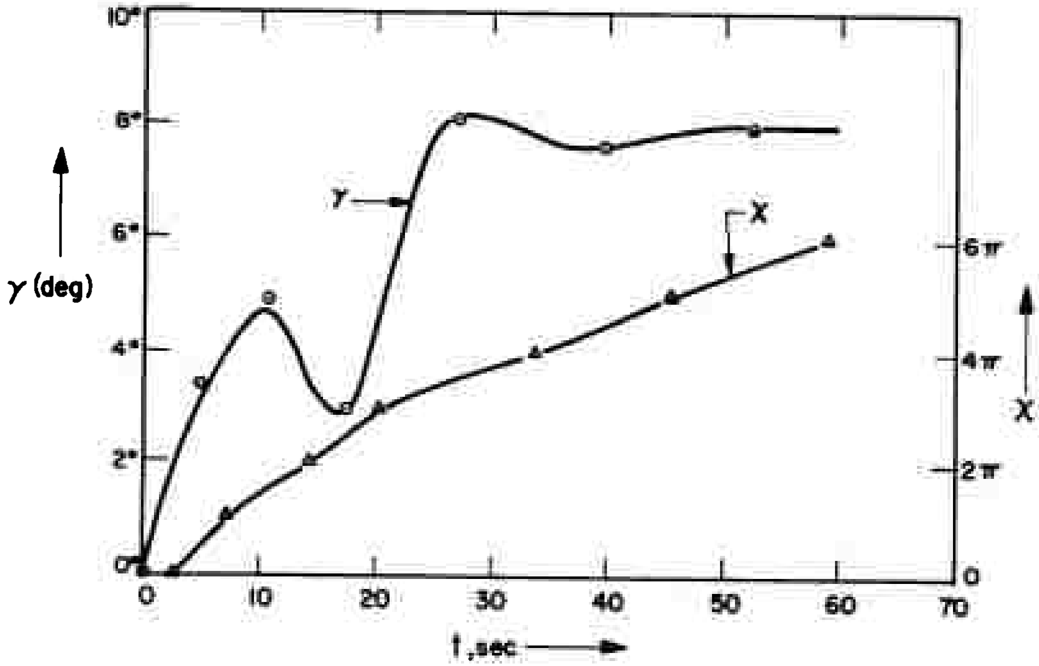


Figure 2.10 Cone half-angle γ and coning azimuthal angle χ versus time, Rocket 19.

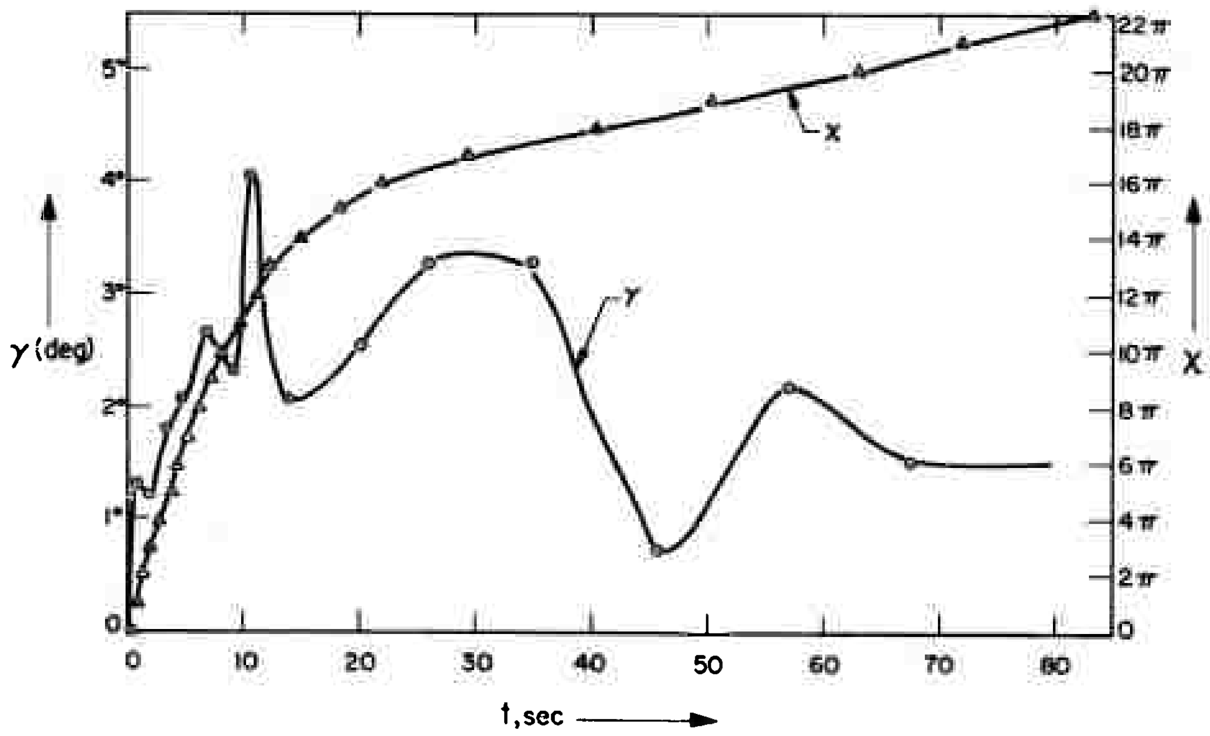


Figure 2.11 Cone half-angle γ and coning azimuthal angle χ versus time, Rocket 26.

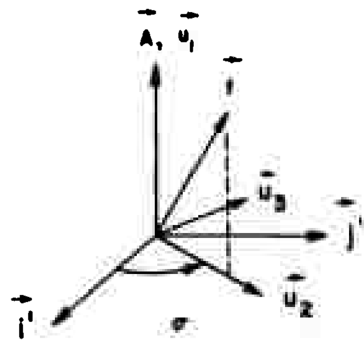


Figure 2.12 Definition of $\vec{u}_1$, $\vec{u}_2$, and $\vec{u}_3$.

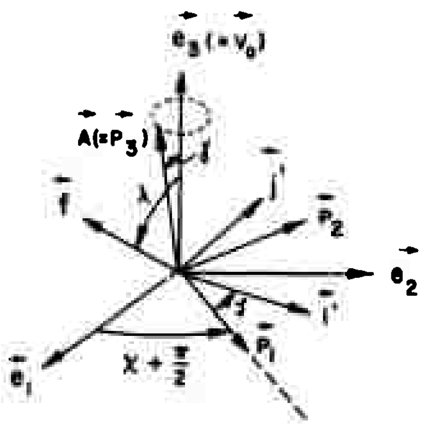


Figure 2.13 Definition of $\vec{p}_1$, $\vec{p}_2$, and $\vec{p}_3$.

CHAPTER 3

COMPUTING PROGRAM DESCRIPTION

3.1 INTRODUCTION

The attitude determination program described in this chapter was designed through modification of a similar program constructed by General Electric for the same purpose. The program computes detector directions in the manner developed in the theoretical discussion of attitude determination in the previous chapter, and the mathematical symbols and computer symbols are related wherever possible.

The data tapes for this program were produced by General Electric by analog-to-digital conversion of telemetry data. Considerable patching of the tapes was apparently necessary to eliminate noise from the digital information. The discontinuities produced by this patching required special data-smoothing techniques to avoid smoothing continuously over the discontinuities. This smoothing process was performed on all digital tapes, and computer program data input tapes were produced for each rocket.

The data processing with the attitude determination program was done at Service Bureau Corporation in El Segundo, California, on an IBM 7094 computer. Three sets of data printout and one input tape for the 3850 Data Analysis Program were produced for Rockets 8, 9, 15, and 26. The data from the remaining Rockets 18, 19, and 29 were not processed for the reasons outlined in the previous chapter.

The processed data are unclassified; however, certain classified inputs were necessary to the computer program. These inputs are discussed in Reference 2.

3.2 DATA SMOOTHING PROGRAM

The smoothing program consists of a main control program with associated subprograms that will smooth data on multiple tapes. The program checks for time discontinuities and makes appropriate changes in the procedure for removing bias and in the use of the appropriate smoothing formulas.

Separate routines were written for input, output, data scanning, actual smoothing, and bias determination.

The procedure for the smoothing of the data was a third-degree seven-point least squares method. The formulas used were obtained from Reference 3. The coefficients of the seven smoothing formulas were arranged in the seven- by seven-square matrix A (by subroutine ARRAY), and then the smoothing was performed by forming a vector $\bar{x}$ of seven functional values to be smoothed and multiplying this vector by the matrix A to obtain a vector $\bar{y}$ of smoothed points, i.e.,

$$\bar{y} = A\bar{x}$$

The center smoothing formula was used on all points that were at least three points away from a data discontinuity. After the smoothing of a block of continuous points, the bias for the particular block was determined and removed, and the block was then output.

3.2.1 Main Control Program. This program is written in Fortran II for the IBM 7094 and acts as a monitor for several subprograms. The program inputs start and stop times for smoothing and printing, run numbers, and tape reel numbers. In order to accomplish a multiple-tape input capability with a minimum of operator setup error, on-line messages are given to the machine operator concerning where and when specific tapes are to be mounted for input.

3.2.2 Subroutine SMOOTH. This routine written in Fortran II performs the actual smoothing of the data and transmits the smooth

data to the output subroutine. The routine calls subroutine ARRAY to initialize the smoothing operator and then uses this matrix to do the smoothing. The matrix A consists of the coefficients in the following equations:

$$y_{i-3} = \frac{1}{42}\,(39x_{i-3} + 8x_{i-2} - 4x_{i-1} - 4x_i + x_{i+1} + 4x_{i+2} - 2x_{i+3})$$

$$y_{i-2} = \frac{1}{42}\,(\ 8x_{i-3} +19x_{i-2} +16x_{i-1} + 6x_i - 4x_{i+1} - 7x_{i+2} + 4x_{i+3})$$

$$y_{i-1} = \frac{1}{42}\,(-4x_{i-3} +16x_{i-2} +19x_{i-1} +12x_i + 2x_{i+1} - 4x_{i+2} + x_{i+3})$$

$$y_i = \frac{1}{21}\,(-2x_{i-3} + 3x_{i-2} + 6x_{i-1} + 7x_i + 6x_{i+1} + 3x_{i+2} - 2x_{i+3})$$

$$y_{i+1},\ y_{i+2},\ y_{i+3}\ \cdots\cdots$$

where y_i is the smooth value corresponding to x_i, which is the center point of the seven points considered by the smoothing values.

The first three equations were used on the first three data points following a discontinuity, the last three on the last three data points before a discontinuity, and the center one on all other points.

3.2.3 Subroutine ARRAY. This routine is written in FAP and is executed only once at the beginning of the program execution. It initializes the smoothing matrix A which consists of the coefficients of the smoothing formulas.

3.2.4 Subroutine SCAN. This subroutine written in Fortran II calls the input subroutine and scans the data to find a sequence of continuous points. Once it finds at least seven consecutive points it calls subroutine SMOOTH to perform the actual smoothing, and then scans ahead to find the next discontinuity.

3.2.5 Subroutine GET. This buffered input routine is written in FAP for the 7094. It reads in a block of 200 data vectors into core storage and makes this matrix available to both the LOAD subroutine and the SCAN subroutine. The routine also checks for tape reading

errors and makes five attempts to read the tape. If after five tries the error remains, the record is skipped and input continues.

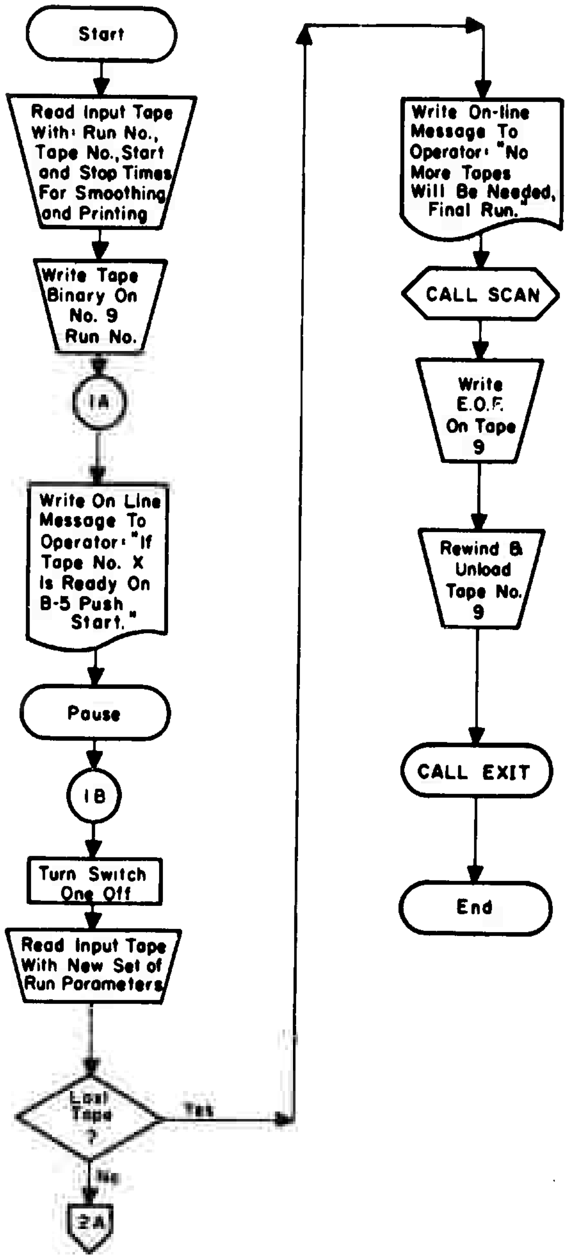
3.2.6 Subroutine OUTPUT. This Fortran II subroutine prepares a block of 100 output vectors for storing on binary output tape and printing on BCD print tape. It determines the amount of bias in the smoothed data by finding the minimum and maximum points on the x and y magnetometer values and calling subroutine PARAB to pass a least squares parabola through five points including the minimum or maximum point as the center one and finding the minimum or maximum of this curve. Once it has obtained the best estimate of the minimum and maximum, the bias is then removed from the whole output block.

3.2.7 Subroutine ERROR. This subroutine writes BCD error message on output tape 6, when errors occur on reading the binary input tapes.

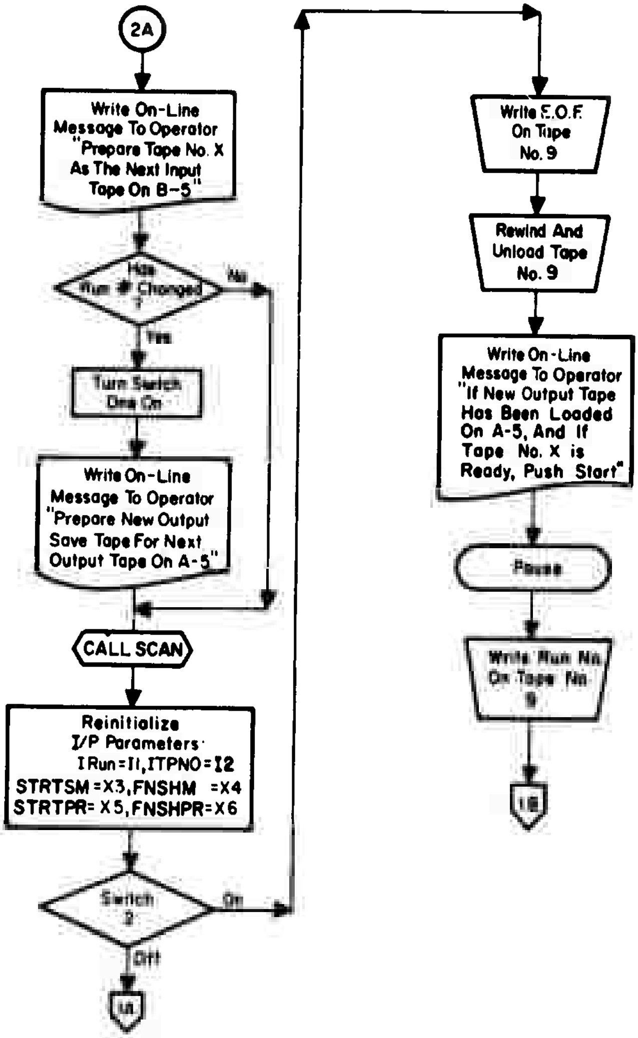
3.2.8 Subroutine PARAB. This subroutine is written in Fortran II and determines the minimum or maximum of a least squares parabola fitted to five points which contain the argument point as its center.

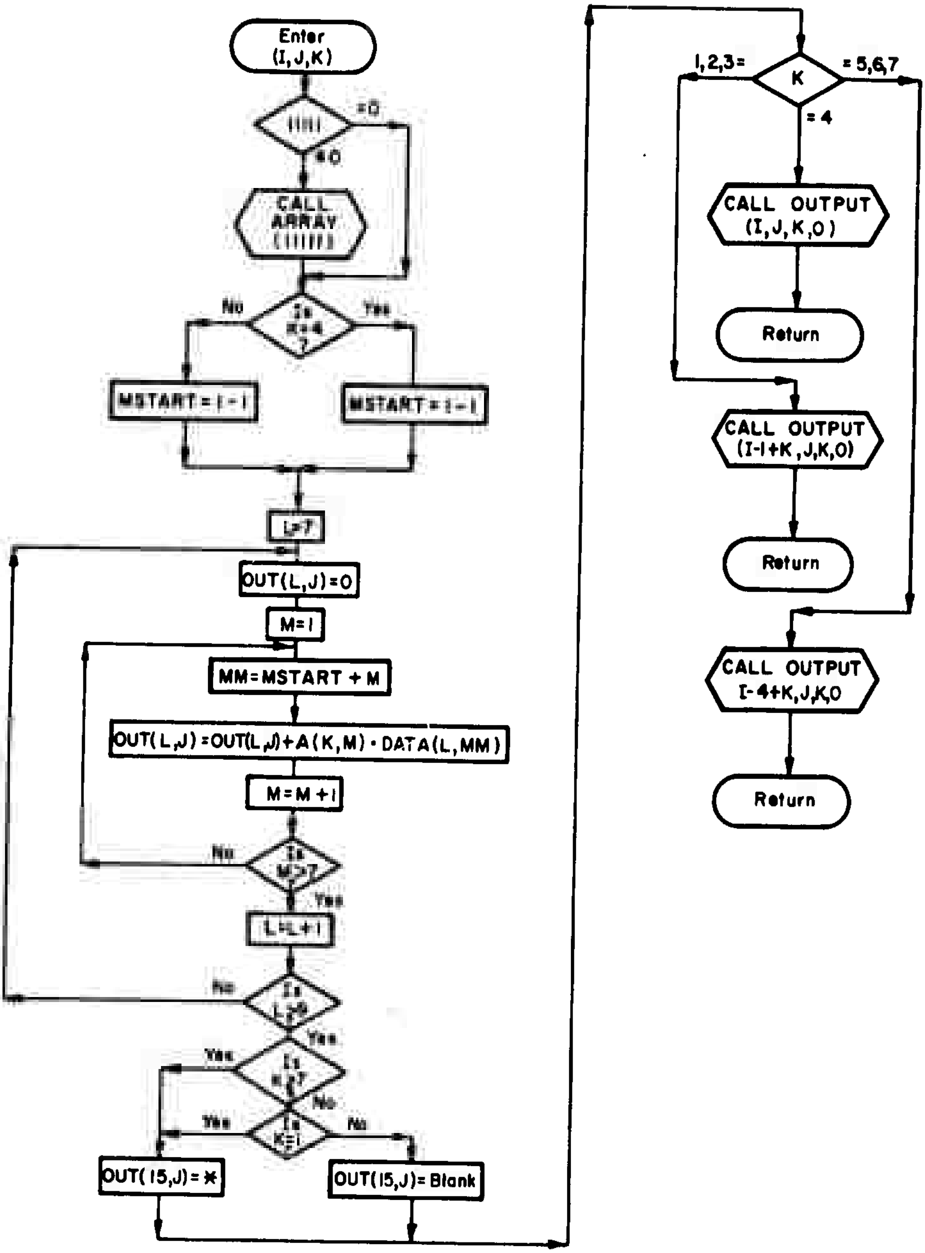
3.2.9 Subroutine LOAD. Subroutine LOAD is written in Fortran II. This routine covers the special case when a discontinuity appears within seven points of the last point in an input array. To handle this situation subroutine LOAD will call subroutine GET to input a new block of points and place the remaining points of the last block in front of the new block and return control to subroutine SCAN.

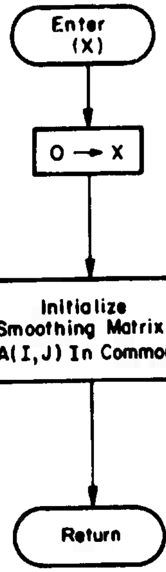
3.2.10 Flow Diagrams. The following diagrams outline the logical and computational processes for each of the routines discussed above and are followed by the program coding as stated in Fortran.

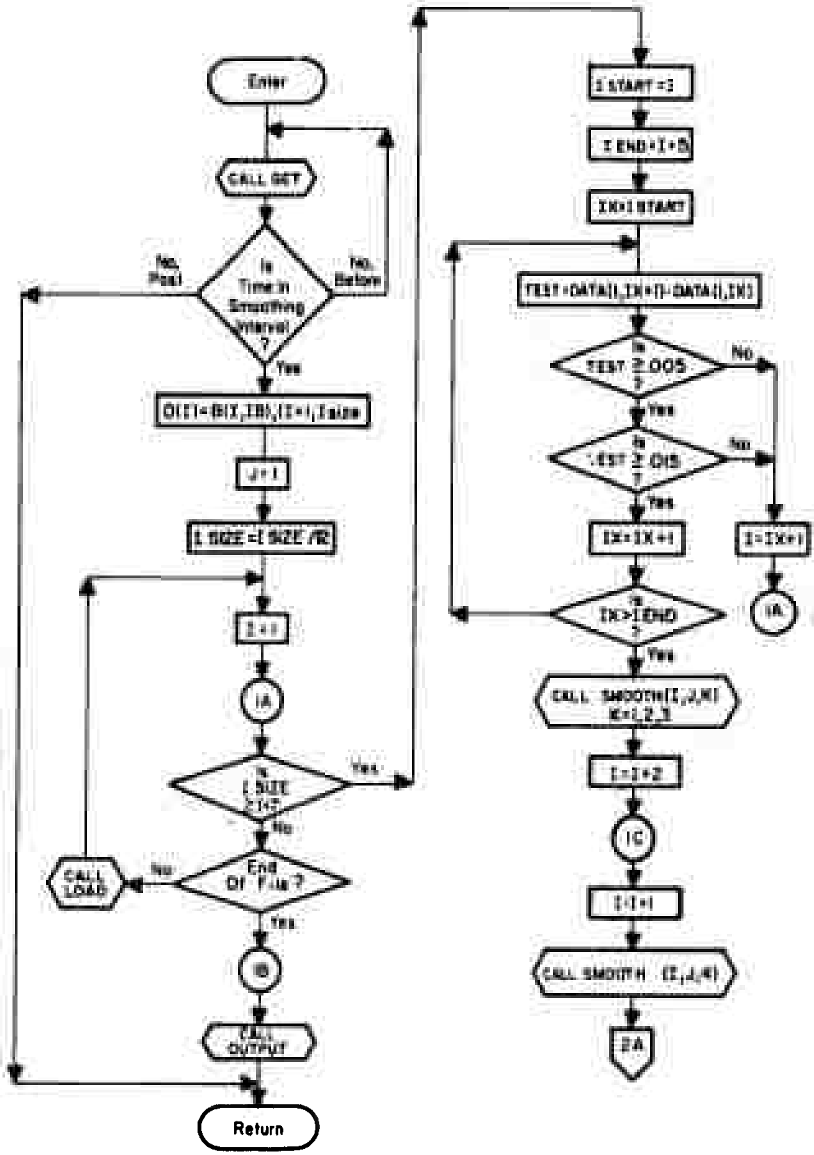


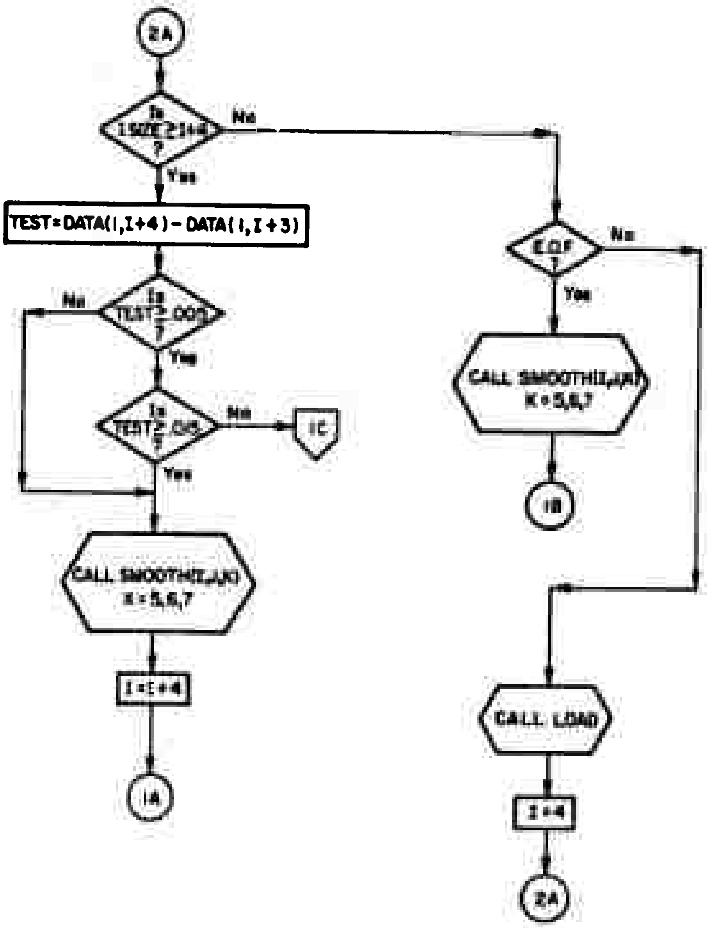
Start
Read Input Tape With: Run No., Tape No., Start and Stop Times For Smoothing and Printing
Write Tape Binary On No. 9 Run No.
1A
Write On Line Message To Operator: "If Tape No. X Is Ready On B-5 Push Start."
Pause
1B
Turn Switch One Off
Read Input Tape With New Set of Run Parameters
Last Tape ?
Yes
No
2A
Write On-line Message To Operator: "No More Tapes Will Be Needed, Final Run."
CALL SCAN
Write E.O.F. On Tape 9
Rewind & Unload Tape No. 9
CALL EXIT
End

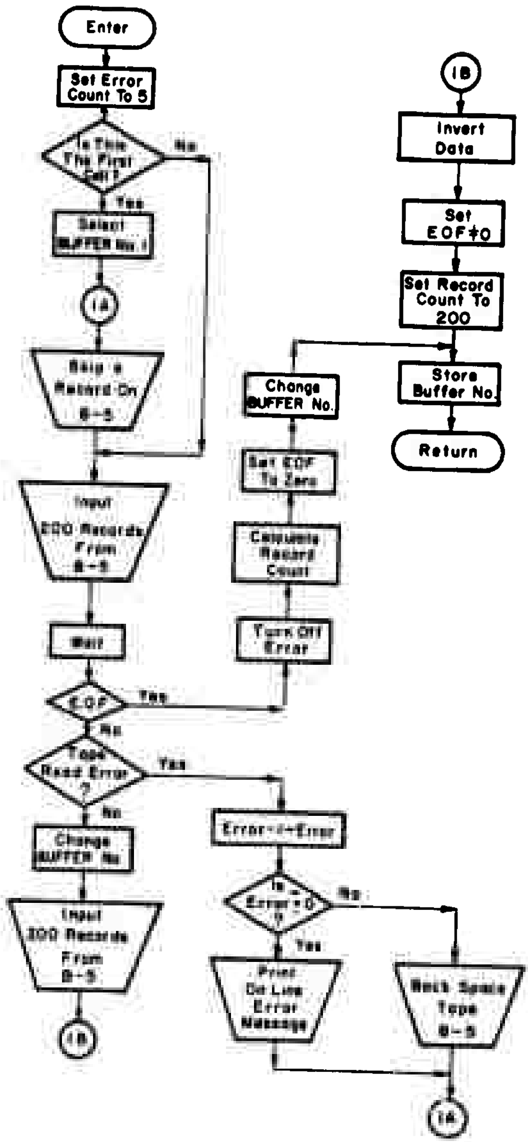

2A
Write On-Line Message To Operator "Prepare Tape No. X As The Next Input Tape On B-5"
Has Run # Changed ?
No
Yes
Turn Switch One On
Write On-Line Message To Operator "Prepare New Output Save Tape For Next Output Tape On A-5"
CALL SCAN
Reinitialize I/P Parameters
IRun=I1,ITPNO=I2
STRTSM=X3,FNSHM =X4
STRTPR= X5,FNSHPR=X6
Switch ?
On
Off
Write E.O.F. On Tape No. 9
Rewind And Unload Tape No. 9
Write On-Line Message To Operator "If New Output Tape Has Been Loaded On A-5, And If Tape No. X is Ready, Push Start"
Pause
Write Run No. On Tape No. 9
1B


Enter
(I,J,K)
=0
≠0
CALL
ARRAY
No
Yes
L=7
OUT(L,J)=0
M=1
MM=MSTART + M
OUT(L,J) =OUT(L,J)+A(K,M) · DATA(L,MM)
M=M+1
No
Yes
L=L+1
No
Yes
Yes
No
Yes
No
OUT(15,J)=*
OUT(15,J)= Blank
K
1,2,3=
=5,6,7
=4
CALL OUTPUT
(I,J,K,0)
Return
CALL OUTPUT
(I-1+K,J,K,0)
Return
CALL OUTPUT
I-4+K,J,K,0
Return

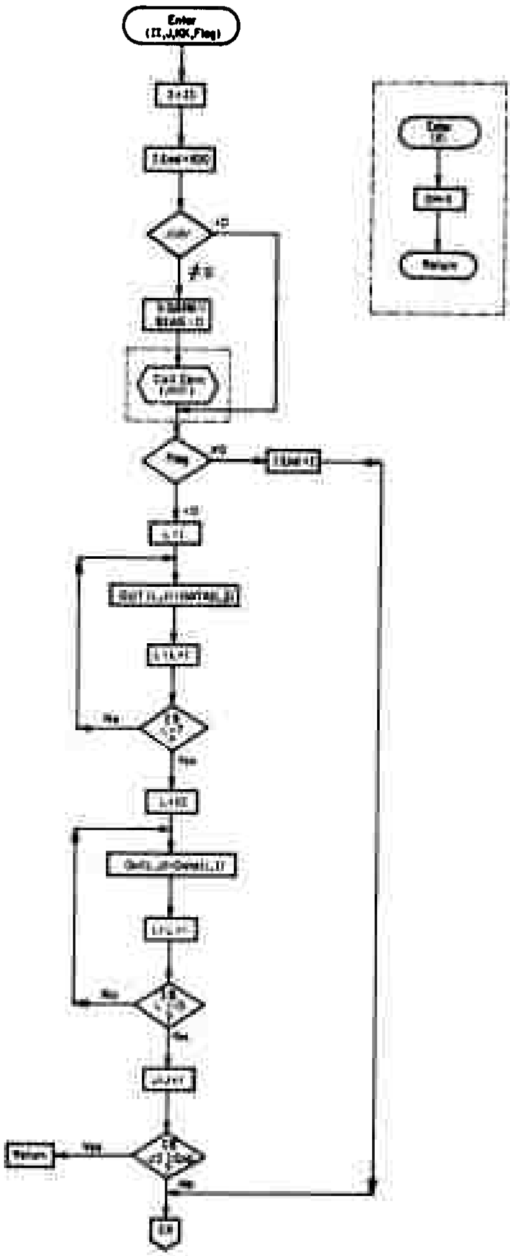

Enter (X)
0 → X
Initialize Smoothing Matrix A(I,J) In Common
Return

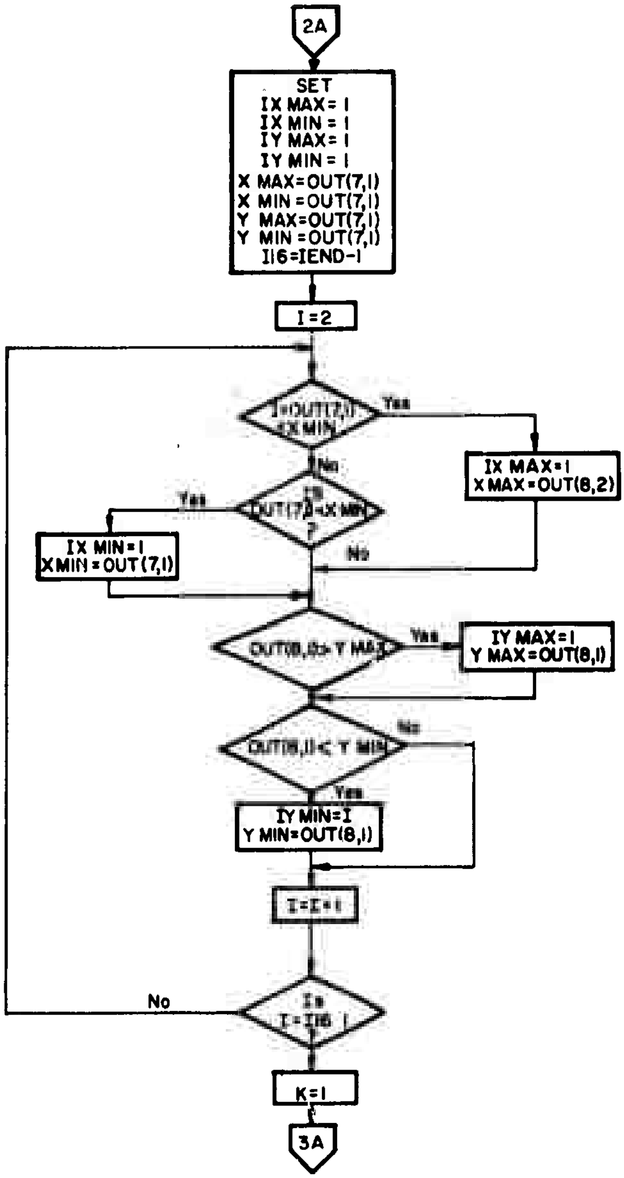

Enter
CALL GET
Is Time in Smoothing Interval ?
No, Past
No, Before
Yes
Return
CALL OUTPUT
CALL LOAD
End Of File ?
I START = I
TEST ≥ .005
TEST ≥ .015
IX = IX + 1
IX > IEND
CALL SMOOTH (I, J, K) K = 1, 2, 3
I = I + 2
I = I + 1
2A

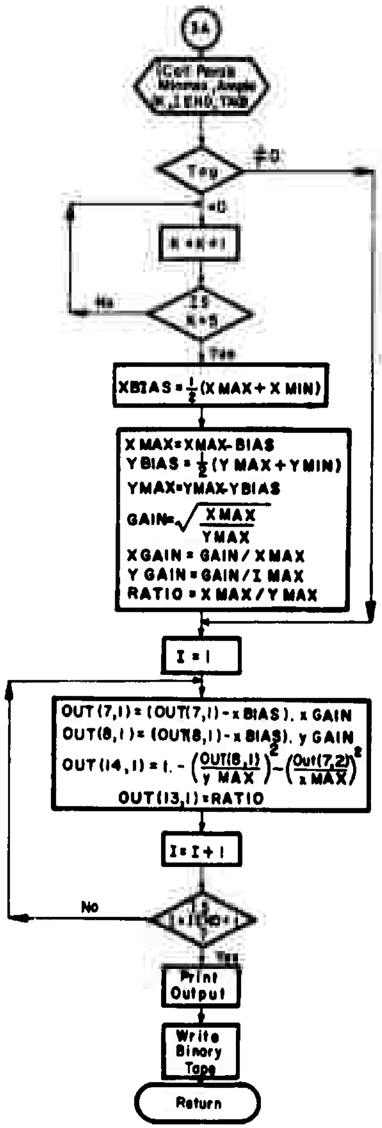

2A
Is ISIZE ≥ I+4 ?
No
Yes
TEST=DATA(I,I+4)-DATA(I,I+3)
Is TEST ≥ .005 ?
No
Yes
Is TEST ≥ .015 ?
No
Yes
1C
CALL SMOOTH(I,J,K) K=5,6,7
I=I+4
1A
E.O.F ?
No
Yes
CALL SMOOTH(I,J,K) K=5,6,7
1B
CALL LOAD
I=4
2A



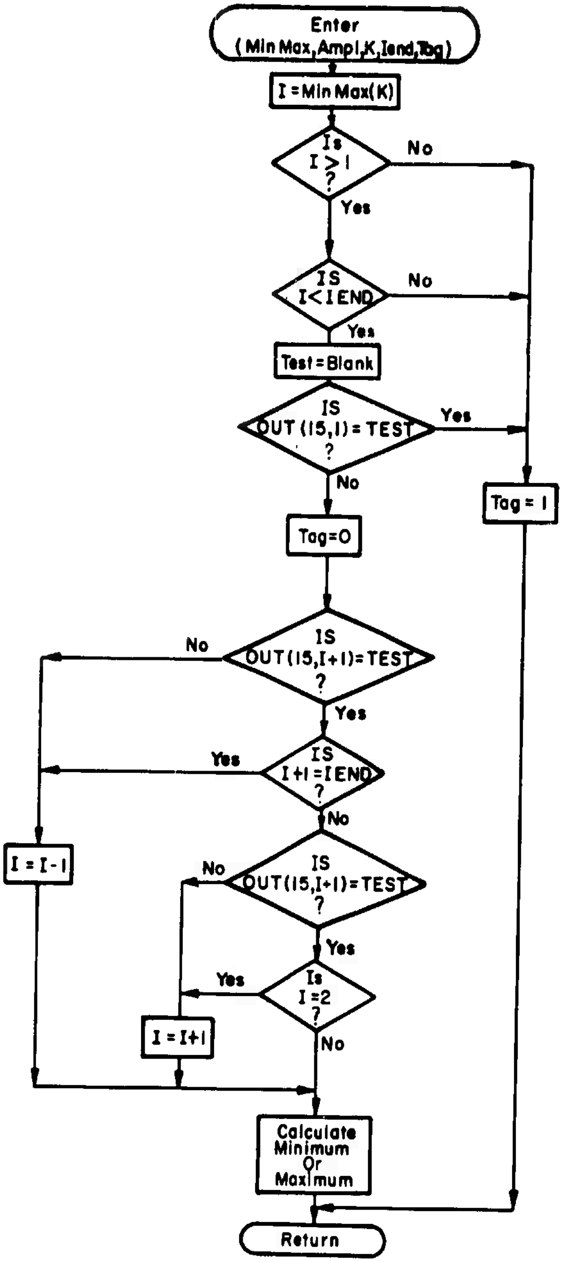
Enter
Set Error Count To 5
Is This The First Call ?
No
Yes
Select BUFFER No. 1
1A
Skip a Record On B-5
Input 200 Records From B-5
Wait
EOF
Yes
No
Tape Read Error ?
Yes
No
Change BUFFER No.
Input 200 Records From B-5
1B
Error-1→Error
Is Error = 0 ?
No
Yes
Print On Line Error Message
Back Space Tape B-5
1A
Turn Off Error
Calculate Record Count
Set EOF To Zero
Change BUFFER No.
1B
Invert Data
Set EOF ≠ 0
Set Record Count To 200
Store Buffer No.
Return


Enter
(II,J,KK,Flag)
Flag
No
Yes
Return

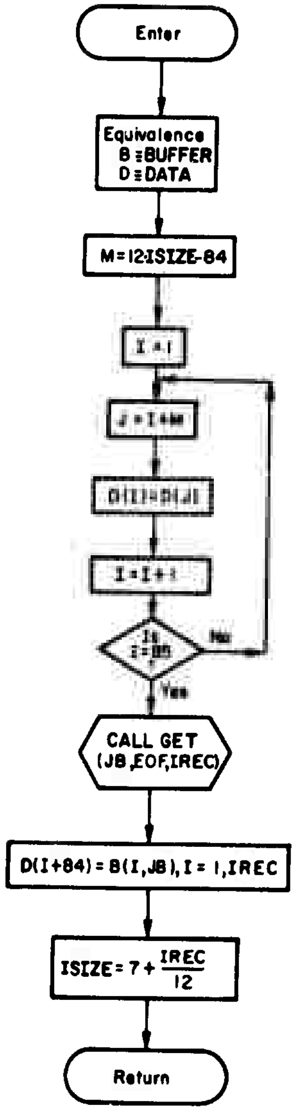

2A
SET
IX MAX= I
IX MIN = I
IY MAX= I
IY MIN = I
X MAX=OUT(7,I)
X MIN =OUT(7,I)
Y MAX=OUT(7,I)
Y MIN =OUT(7,I)
I16=IEND-I
I=2
IX MAX=I
X MAX=OUT(8,2)
IX MIN=I
XMIN=OUT(7,I)
IY MAX=I
Y MAX=OUT(8,I)
IY MIN=I
Y MIN=OUT(8,I)
No
K=I
3A



3A
≠0
=0
No
Yes
XBIAS = 1/2 (X MAX + X MIN)
X MAX = XMAX - BIAS
Y BIAS = 1/2 (Y MAX + Y MIN)
YMAX = YMAX - YBIAS
GAIN = √(XMAX / YMAX)
X GAIN = GAIN / X MAX
Y GAIN = GAIN / I MAX
RATIO = X MAX / Y MAX
I = 1
OUT(7,I) = (OUT(7,I) - x BIAS). x GAIN
OUT(8,I) = (OUT(8,I) - x BIAS). y GAIN
OUT(14,I) = 1. - (OUT(8,I) / y MAX)^2 - (Out(7,2) / x MAX)^2
OUT(13,I) = RATIO
I = I + 1
No
Yes
Print Output
Write Binary Tape
Return



Enter
(Min Max, Ampl, K, Iend, Tag)
I = Min Max(K)
Is
I > I
?
No
Yes
IS
I < I END
No
Yes
Test = Blank
IS
OUT (15, I) = TEST
?
Yes
No
Tag = I
Tag = O
IS
OUT (15, I+1) = TEST
?
No
Yes
IS
I+I = I END
?
Yes
No
I = I-I
IS
OUT (15, I+1) = TEST
?
No
Yes
Is
I = 2
?
Yes
No
I = I+I
Calculate
Minimum
Or
Maximum
Return



Enter
Equivalence
B ≡ BUFFER
D ≡ DATA
M = 12·ISIZE-84
I = 1
J = I+M
D(I)=D(J)
I=I+1
No
Yes
CALL GET
(JB,EOF,IREC)
D(I+84) = B(I,JB), I = 1,IREC
ISIZE = 7 + IREC/12
Return

```
C       MAIN PROGRAM FOR DATA SMOOTHING
        DIMENSION BUFFER(12,200,2),DATA(12,207),OUT(15,200),B(2400,2),
       1D(2484)
        COMMON BUFFER,DATA,OUT,IRUN,STRTSM,FNSHSM,STRTPR,FNSHPR
        EQUIVALENCE (BUFFER,B),(DATA,D)
        READ INPUT TAPE 5,100,IRUN,ITPNO,STRTSM,FNSHSM,STRTPR,FNSHPR
  100   FORMAT(2I5,4F10.0)
        WRITE TAPE 9, IRUN
  200   PRINT 300, ITPNO
  300   FORMAT(1H111HIF TAPE NO.I5,29H IS READY ON B-5, PUSH START.)
  350   ISW1=1
        PAUSE
        READ INPUT TAPE 5,100,I1,I2,X3,X4,X5,X6
        IF(I1) 400,1100,400
  400   PRINT 500,I2
  500   FORMAT(17H1PREPARE TAPE NO.I5,31H AS THE NEXT INPUT TAPE ON B-5.)
        IF(IRUN-I1)600,800,600
  600   ISW1=2
        PRINT 700
  700   FORMAT(1H173H ***** PREPARE NEW OUTPUT SAVE TAPE FOR THE NEXT OUTP
       1UT TAPE ON A-5.*****)
  800   CALL SCAN
        IRUN=I1
        ITPNO=I2
        STRTSM=X3
        FNSHSM=X4
        STRTPR=X5
        FNSHPR=X6
        GO TO (200,900),ISW1
  900   END FILE 9
        CALL REWULD (9)
        PRINT 1000,ITPNO
 1000   FORMAT(1H142HIF NEW OUTPUT TAPE HAS BEEN LOADED ON A-5./15H AND IF
       1TAPE NO.I5,29H IS READY ON B-5, PUSH START.)
        PAUSE
        WRITE TAPE 9,IRUN
        GO TO 350
 1100   PRINT 1200
 1200   FORMAT(53H1NO MORE TAPES WILL BE NEEDED, THIS IS THE FINAL RUN.)
        CALL SCAN
        END FILE 9
        CALL REWULD (9)
        CALL EXIT
        END
```

```
      SUBROUTINE SMOOTH(I,J,K)
      DIMENSION BUFFER(12,200,2),DATA(12,207),OUT(15,200),B(2400,2),
     1D(2484)
      COMMON BUFFER,DATA,OUT,IRUN,STRTSM,FNSHSM,STRTPR,FNSHPR
      EQUIVALENCE (BUFFER,B),(DATA,D)
      DIMENSION A(7,7)
      IF(11111)10,20,10
   10 CALL ARRAY(11111,A)
   20 IF(K-4)200,300,300
  200 MSTART=I-1
      GO TO 400
  300 MSTART=I-4
  400 DO 1000 L=7,9
  500 OUT(L,J)=0.
  600 DO 900 M=1,7
  700 MM=MSTART+M
  800 OUT(L,J)=OUT(L,J)+A(K,M)*DATA(L,MM)
  900 CONTINUE
 1000 CONTINUE
 1100 IF(K-7)1150,1300,1300
 1150 IF(K-1)1200,1300,1200
B1200 OUT(15,J)=606060606060
      GO TO 1400
B1300 OUT(15,J)=546060606060
 1400 GO TO(1401,1401,1401,1402,1403,1403,1403),K
 1401 CALL OUTPUT(I-1+K,J,K,0)
      GO TO 1500
 1402 CALL OUTPUT(I,J,K,0)
      GO TO 1500
 1403 CALL OUTPUT(I-4+K,J,K,0)
 1500 RETURN
      END
```

```
*        FAP
         COUNT    20
         ENTRY    ARRAY
ARRAY    STZ*     1,4
         CLA      2,4
         ADD      =1
         STA      B2A
         SXA      B3,1
         AXT      49,1
B2       CLA      DATA+49,1
B2A      STO      **,1
         TIX      B2,1,1
B3       AXT      **,1
         TRA      3,4
DATA     DEC      .92857143,.19047619,-.09523810,-.09523810,.02380952
         DEC      .09523810,-.04761905,.19047619,.45238095,.38095238
         DEC      .14285714,-.09523810,-.16666667,.09523810,-.09523810
         DEC      .38095238,.45238095,.28571429,.04761905,-.09523810
         DEC      .02380952,-.09523810,.14285714,.28571429,.33333333
         DEC      .28571429,.14285714,-.09523810,.02380952,-.09523810
         DEC      .04761905,.28571429,.45238095,.38095238,-.09523810
         DEC      .09523810,-.16666667,-.09523810,.14285714,.38095238
         DEC      .45238095,.19047619,-.04761905,.09523810,.02380952
         DEC      -.09523810,-.09523810,.19047619,.92857143
         END
```

```
      SUBROUTINE SCAN
      DIMENSION BUFFER(12,200,2),DATA(12,207),OUT(15,200),B(2400,2),
     1D(2484)
      COMMON BUFFER,DATA,OUT,IRUN,STRTSM,FNSHSM,STRTPR,FNSHPR
      EQUIVALENCE (BUFFER,B),(DATA,D)
  100 CALL GET(IB,EOF,ISIZE)
  110 IF(STRTSM-BUFFER(1,200,IB))120,120,100
  120 IF(FNSHSM-BUFFER(1,1,IB))130,130,140
  130 RETURN
  140 CONTINUE
      DO 150 I=1,ISIZE
  150 D(I)=B(I,IB)
      J=1
      ISIZE=ISIZE/12
  200 I=1
  300 IF(ISIZE-I-7)400,700,700
  400 IF(EOF)600,500,600
  500 CALL OUTPUT (I,J,K,1.)
      RETURN
  600 CALL LOAD(ISIZE,EOF)
      GO TO 200
  700 ISTART=I
      IEND=I+5
      DO 740 IX=ISTART,IEND
      TEST=DATA(1,IX+1)-DATA(1,IX)
  710 IF(TEST-.005)750,720,720
  720 IF(TEST-.015)740,740,750
  740 CONTINUE
      GO TO 800
  750 I=IX+1
      GO TO 300
  800 DO 1000 K=1,3
 1000 CALL SMOOTH(I,J,K)
 1100 I=I+2
 1200 I=I+1
 1300 CALL SMOOTH(I,J,4)
 1400 IF(ISIZE-I-4)2000,1500,1500
 1500 TEST=DATA(1,I+4)-DATA(1,I+3)
      IF(TEST-.005)1600,1510,1510
 1510 IF(TEST-.015)1200,1600,1600
 1600 DO 1800 K=5,7
 1800 CALL SMOOTH(I,J,K)
 1900 I=I+4
      GO TO 300
 2000 IF(EOF)2400,2100,2400
 2100 DO 2300 K=5,7
 2300 CALL SMOOTH(I,J,K)
      GO TO 500
 2400 CALL LOAD(ISIZE,EOF)
      I=4
      GO TO 1400
      END
```

```
*       FAP
*GET    SUBROUTINE FOR INPUT
        COUNT   50
        ENTRY   GET
        ENTRY   ZERO
 ZERO   STZ*    1,4
        TRA     2,4
 GET    LMTM
        AXT     5,3
        NZT     FIRST
        TRA     B5
 B3     STZ     FIRST
        AXT     1,5
        SXD     BUFNO,5
        RTDB    5
        RCHB    SKIP
        TCOB    *
        TRCB    *+1
 B4     RTBB    5
        RCHB    INPUT,5
 B5     TCOB    *
 B7     TEFB    B16
        TRCB    B13
 B9     LDC     BUFNO,5
        SXD     BUFNO,5
 B10    RTBB    5
        RCHB    INPUT,5
 B6     LDC     BUFNO,5
        AXT     SIZE6,6
        AXT     1,7
 B6A    TXL     B6B,5,1
        CLA     BUFER2+SIZE6,6
        LDQ     BUFER2+SIZE12,7
        STO     BUFER2+SIZE12,7
        STQ     BUFER2+SIZE6,6
        TRA     B6C
 B6B    CLA     BUFER1+SIZE6,6
        LDQ     BUFER1+SIZE12,7
        STO     BUFER1+SIZE12,7
        STQ     BUFER1+SIZE6,6
 B6C    TXI     *+1,7,1
        TIX     B6A,6,1
 B11    STL*    2,4
        CLA     TWO
 B11A   STO*    3,4
        LXD     BUFNO,5
        CLA     BUFER,5
        STO*    1,4
 B12    EMTM
        TRA     4,4
 B13    TNX     B15,3,1
 B14    AXT     SIZE,6
        BSRB    5
        TIX     *-1,6,1
        TRA     B4
 B16    TRCB    *+1
        SCHB    COUNT
        CLA     INPUT,5
        SUB     COUNT
```

```
         STZ*    2,4
         RUNB    5
         STL     FIRST
         LDC     BUFNO,5
         SXD     BUFNO,5
         TRA     B11A
B15      SXA     *+2,4
         TSX     $ERROR,4
         AXT     **,4
         TRA     B4
*     CONSTANTS  AND SYMBOLS
SIZE     EQU     200
SIZE12   EQU     SIZE*12
FIRST    PZE     1
SKIP     IOCD    0,0,0
         IOCD    BUFER1,0,SIZE12
INPUT    PZE
         IOCD    BUFER2,0,SIZE12
BUFNO    EQU     INPUT
         PZE     0,0,1
BUFER    PZE
         PZE     0,0,2
SIZE6    EQU     SIZE*6
TWO      PZE     0,0,SIZE12
COUNT    EQU     FIRST
BUFER1   EQU     32562-SIZE12*2
BUFER2   EQU     32562-SIZE12
         END
      SUBROUTINE ERROR
      WRITE OUTPUT TAPE 6,1
      RETURN
    1 FORMAT(5X27HERROR IN READING INPUT TAPE)
      END
```

```
      SUBROUTINE OUTPUT(II,J,KK,FLAG)
      DIMENSION BUFFER(12,200,2),DATA(12,207),OUT(15,200),B(2400,2),
     1D(2484)
      COMMON BUFFER,DATA,OUT,IRUN,STRTSM,FNSHSM,STRTPR,FNSHPR
      EQUIVALENCE (BUFFER,B),(DATA,D)
      DIMENSION MINMAX(4),AMPL(4)
      EQUIVALENCE(MINMAX(1),IXMIN),(MINMAX(2),IXMAX),(MINMAX(3),IYMIN),
     1(MINMAX(4),IYMAX),(AMPL(1),XMIN),(AMPL(2),XMAX),(AMPL(3),YMIN),
     2(AMPL(4),YMAX)
      I=II
      IEND=100
      IF(I1111) 50,100,50
   50 XGAIN=1.
      YGAIN=1.
      BIAS=0.
      CALL ZERO (I1111)
  100 IF(FLAG)200,300,200
  200 IEND=J
      GO TO 600
  300 DO 320 L=1,6
  320 OUT(L,J)=DATA(L,I)
      DO 350 L=10,12
  350 OUT(L,J)=DATA(L,I)
  400 J=J+1
  500 IF(J-IEND)2700,2700,600
  600 IXMAX=1
      IXMIN=1
      IYMAX=1
      IYMIN=1
      XMAX=OUT(7,1)
      XMIN=OUT(7,1)
      YMAX=OUT(8,1)
      YMIN=OUT(8,1)
      I1600=IEND-1
  700 DO 1600 I=2,I1600
  800 IF(OUT(7,I)-XMAX)1000,1000,900
  900 IXMAX=I
      XMAX=OUT(7,I)
      GO TO 1200
 1000 IF(OUT(7,I)-XMIN)1100,1200,1200
 1100 IXMIN=I
      XMIN=OUT(7,I)
 1200 IF(OUT(8,I)-YMAX)1400,1400,1300
 1300 IYMAX=I
      YMAX=OUT(8,I)
      GO TO 1600
 1400 IF(OUT(8,I)-YMIN)1500,1600,1600
 1500 IYMIN=I
      YMIN=OUT(8,I)
 1600 CONTINUE
 1700 DO 2000 K=1,4
 1800 CALL PARAB(MINMAX,AMPL,K,IEND,TAG)
      IF(TAG)2200,2000,2200
 2000 CONTINUE
 2100 XBIAS=.5*(XMAX+XMIN)
      XMAX=XMAX-XBIAS
      YBIAS=.5*(YMAX+YMIN)
      YMAX=YMAX-YBIAS
      GAIN=SQRTF(XMAX*YMAX)
```

```
      XGAIN=GAIN/XMAX
      YGAIN=GAIN/YMAX
      RATIO=XMAX/YMAX
 2200 DO 2400 I=1,IEND
      OUT(7,I)=(OUT(7,I)-XBIAS)*XGAIN
      OUT(8,I)=(OUT(8,I)-YBIAS)*YGAIN
      OUT(14,I)=1.-(OUT(8,I)/YMAX)**2-(OUT(7,I)/XMAX)**2
 2400 OUT(13,I)=RATIO
C     OUTPUT ROUTINE
      IF(STRTPR-OUT(1,IEND))2450,3050,3050
 2450 IF(FNSHPR-OUT(1,1))3050,2500,2500
 2500 WRITE OUTPUT TAPE 6,2600,IRUN
 2600 FORMAT (43H1OUTPUT FROM DATA SMOOTHING PROGRAM RUN NO.I3,18HEOS -
     1M RUBINSTEIN///6X4HTIME13X1HY15X1HX15X1HZ13X5HRATIO12X4HDIFF8X4HCO
     2DE)
      IF(50-IEND)3100,2800,2800
 2800 DO 2900 KK=1,IEND
 2900 WRITE OUTPUT TAPE 6,3000,OUT(1,KK),OUT(7,KK),OUT(8,KK),OUT(9,KK),O
     1UT(13,KK),OUT(14,KK),OUT(15,KK)
 3000 FORMAT(F12.4,F14.4,2F16.4,2F16.3,10XA1)
 3050 WRITE TAPE 9,IEND,((OUT(I,J),I=1,15),J=1,IEND)
      J=1
 2700 RETURN
 3100 DO 3200 KK=1,50
 3200 WRITE OUTPUT TAPE 6,3000,OUT(1,KK),OUT(7,KK),OUT(8,KK),OUT(9,KK),O
     1UT(13,KK),OUT(14,KK),OUT(15,KK)
      WRITE OUTPUT TAPE 6,2600,IRUN
      DO 3300 KK=51,IEND
 3300 WRITE OUTPUT TAPE 6,3000,OUT(1,KK),OUT(7,KK),OUT(8,KK),OUT(9,KK),O
     1UT(13,KK),OUT(14,KK),OUT(15,KK)
      WRITE TAPE 9,IEND,((OUT(I,J),I=1,15),J=1,IEND)
      J=1
      RETURN
      END
```

```
      SUBROUTINE PARAB(MINMAX,AMPL,K,IEND,TAG)
      DIMENSION BUFFER(12,200,2),DATA(12,207),OUT(15,200),B(2400,2),
     1D(2484)
      COMMON BUFFER,DATA,OUT,IRUN
      EQUIVALENCE (BUFFER,B),(DATA,D)
      DIMENSION MINMAX(4),AMPL(4)
  100 I=MINMAX(K)
      IF(I-1)300,300,400
  300 TAG=1.
      GO TO 1400
  400 IF(I-IEND)500,300,300
B 500 TEST=606060606060
      IF(OUT(15,I)-TEST)300,600,300
  600 TAG=0.
  700 IF(OUT(15,I+1)-TEST)800,900,800
  800 I=I-1
      GO TO 1300
  900 IF(I+1-IEND)1000,800,1000
 1000 IF(OUT(15,I-1)-TEST)1100,1200,1100
 1100 I=I+1
      GO TO 1300
 1200 IF(I-2)1300,1100,1300
 1300 L=(13+K)/2
      A0=(-6.*(OUT(L,I-2)+OUT(L,I+2))+24.*(OUT(L,I-1)+OUT(L,I+1))
     1+34.*OUT(L,I))/70.
      A1=(14.*(OUT(L,I+2)-OUT(L,I-2))+7.*(OUT(L,I+1)-OUT(L,I-1)))/70.
      A2=(10.*(OUT(L,I-2)-OUT(L,I)+OUT(L,I+2))-5.*(OUT(L,I-1)+OUT(L,I+1)
     1))/70.
      AMPL(K)=A0-.25*A1*A1/A2
 1400 RETURN
      END
```

```
CLOAD    SUBROUTINE FOR LOADING INPUT DATA FROM BUFFER
      SUBROUTINE LOAD(ISIZE,EOF)
      DIMENSION BUFFER(12,200,2),DATA(12,207),OUT(15,200),B(2400,2),
     1D(2484)
      COMMON BUFFER,DATA,OUT,IRUN,STRTSM,FNSHSM,STRTPR,FNSHPR
      EQUIVALENCE (BUFFER,B),(DATA,D)
      M=12*ISIZE-84
      DO 100 I=1,84
      J=I+M
  100 D(I)=D(J)
      CALL GET(JB,EOF,IREC)
      DO 200 I=1,IREC
  200 D(I+84)=B(I,JB)
      ISIZE=7+(IREC/12)
      RETURN
      END
```

3.3 ATTITUDE DETERMINATION PROGRAM

3.3.1 Main Program. The main program is an executive program which controls all input/output and calls the main subprograms into action. This program is written in Fortran II for the IBM 7094 and uses a buffered input/output on both BCD and binary tape commands.

The program begins by initializing constants for the MAGNET subroutine, the detector angles, and associated trigonometric functions. The program continues and inputs a classified card, control cards with parameters for the specific rocket, and gamma and beta energy conversion tables. All inputs with the exception of the classified information are then output for printing. The main loop of the program starts at this point, and the binary input tape with smoothed magnetometer data is read into core where the start and stop times are checked for processing.

Reading of the binary input tape continues until the systems time on this tape equals the start time indicated by the control card. A test is then made to determine if the systems time read-in falls in the perturbed interval (TLA to TLB) and is greater than the atmosphere exit time, and switches are set accordingly. Subroutine TRAJ is now called to compute the coning axis vector, as a function of the current systems time if it is less than or equal to the atmosphere exit time. This procedure guarantees that the coning axis is constant above the atmosphere. TRAJ is called once more to calculate the payload position in Johnston Island (J I) coordinates.

The payload position is needed in order to determine the theoretical magnetic field at that position with the use of the MAGNET subroutine. The MAGNET subroutine must be given the position in a

latitude-longitude coordinate system and consequently, the first coordinate transformation is performed. The transformation matrix is defined in terms of the launch latitude ψ_L and launch longitude λ_L east of Greenwich as follows:

$$G = \begin{bmatrix} -\sin\lambda_L & -\sin\psi_L \cos\lambda_L & \cos\psi_L \cos\lambda_L \\ \cos\lambda_L & -\sin\psi_L \sin\lambda_L & \cos\psi_L \sin\lambda_L \\ 0 & \cos\psi_L & \sin\psi_L \end{bmatrix}$$

A vector $\vec{x}$ in J I coordinates is expressed in geocentric coordinates by

$$\vec{x}' = G\,\vec{x}$$

The latitude and longitude are now computed using

$$\psi_p = \text{lat} = \tan^{-1}\left(\frac{x_3'}{\sqrt{x_1'^2 + x_2'^2}}\right)$$

$$\lambda_p = \text{long} = \tan^{-1}\left(\frac{x_2'}{x_1'}\right)$$

The elements of the rotation matrix which will rotate the coordinates of a point in the earth's geocentric coordinate system into J I coordinates are now computed. The resulting matrix is linarized since displacements are small compared to one radian, and we then obtain the following where ψ_p is the payload latitude and λ_p is the payload longitude,

$$B = \begin{bmatrix} 1 & -(\lambda_p-\lambda_L)\sin\psi_p & (\lambda_p-\lambda_L)\cos\psi_p \\ (\lambda_p-\lambda_L)\sin\psi_L & 1 & \psi_p-\psi_L \\ -(\lambda_p-\lambda_L)\cos\psi_L & -(\psi_p-\psi_L) & 1 \end{bmatrix}$$

Subroutine MAGNET is now called, and the components of the theoretical field $\vec{x}$, in geocentric coordinates, are then rotated into J I coordinates using matrix B, i.e.,

$$\vec{F}_r = B\,\vec{x}$$

Control is now transferred to the ATUDE subroutine where direction cosines are determined and returned in the form of a matrix called A. This matrix is now used to compute the direction cosines of the detectors in the payload which are in turn used to compute the detector attitudes using the following equations:

$$\Theta_i = \tan^{-1}\left(\frac{z_i}{\sqrt{1 - z_i^2}}\right) \quad \text{(Elev.)}$$

$$\phi_i = \tan^{-1}\left(\frac{x_i}{y_i}\right) \quad \text{(Azim.)}$$

where x_i, y_i, z_i are the x, y, and z direction cosines of the i^{th} detector, and Θ_i and ϕ_i are the elevation and azimuth of the i^{th} detector.

The azimuth and elevation of the burst to payload and rocket axis vector are determined using similar equations.

The main loop of the main program is now completed by using a table look-up method of determining the functional values of the beta and gamma detectors from the energy conversion tables input to the program at the beginning.

All of the computed results are stored on a binary output tape, and an off-line print tape is prepared at this time.

GLOSSARY OF TERMS

Fortran Name	Formula Name	Description
FLAT	ψ_L	launch latitude
FLONG	λ_L	launch longitude
SLAT	$\sin\psi_L$	
CLAT	$\cos\psi_L$	
SLONG	$\sin\lambda_L$	
CLONG	$\cos\lambda_L$	

GLOSSARY OF TERMS (contd.)

Fortran Name	Formula Name	Description
(XP,YP,ZP)	$\vec{x}'$	geocentric coordinates of a vector $\vec{x}$
ELAT	ψ_p	latitude of payload
ELONG	λ_p	longitude of payload
CON1	$\lambda_p-\lambda_L$	factor of element in linearized rotation matrix
CON2	$\psi_p-\psi_L$	factor of element in linearized rotation matrix
CON3	$\sin\psi_p$	factor of element in linearized rotation matrix
CON4	$\cos\psi_p$	factor of element in linearized rotation matrix
FR(I)	$\vec{F}_r$	theoretical field vector
DPHI(I)	Φ_I	azimuth of i^{th} detector
DTHETA(I)	Θ_I	elevation of i^{th} detector
A(I,J)	A	direction cosine matrix
TLA		start time in systems time for the use of the mathematical model in subroutine ATUDE
TLB		stop time in systems time for the use of the mathematical model in subroutine ATUDE

3.3.2 Subroutine ATUDE. Subroutine ATUDE determines the direction cosines of the x, y, and z magnetometers (A_{ij}) in the J I coordinate system.

This subroutine uses the coning axis vector CA and the theoretical magnetic field vector FR as determined in the main program and transmitted in common. The routine also uses the subroutine CONE to obtain the coning parameters GAMMA and BCONE, the half-cone angle and total azimuthal coned angle of CA, respectively.

During the magnetic field perturbation period of the Rocket 19 flight, the spin frequency FREQ and spin phase angle PHASE of the rocket are used in place of the smoothed magnetometer data in the determination of the direction cosines. These two parameters are input by the main program and transmitted in common to this subroutine, which calculates the A_{ij} matrix directly as shown in the flow diagrams for ATUDE.

The A_{ij} matrix is transmitted in common to the main program.

GLOSSARY OF TERMS

Fortran Name	Formula Name	Description
CA(I),R(I)	$\vec{R}$, $\vec{e}_3$	coning axis vector
TL	t	time from launch
S(I)	$\vec{e}_1$	element of $\vec{e}_i$ orthog. syst.
T(I)	$\vec{e}_2$	element of $\vec{e}_i$ orthog. syst.
BCONE	ϕ	the total azimuthal coned angle of $\vec{R}$
GAMMA	γ	half cone angle
A(3,I)	$\vec{A}_3,\vec{U}_1,\vec{P}_3,\vec{K}'$	direction cosines of z magnetometer
ATB(I)	$\vec{U}_2$ or $\vec{P}_1$	$\vec{U}_2$ for nonperturbed period, $\vec{P}_1$ otherwise
ATC(I)	$\vec{U}_3$ or $\vec{P}_2$	$\vec{U}_3$ for nonperturbed period, $\vec{P}_2$ otherwise
A(1,I)	$\vec{i}^1$	
A(2,I)	$\vec{j}^1$	
FR(I)	$\vec{f}$	theoretical field vector
FREQ	μ	rocket spin frequency
PHASE	δ	rocket spin phase angle

3.3.3 Subroutine TRAJ. The purpose of the TRAJ subroutine is to compute the position and velocity of the vehicle during its flight. Since the ground range of the actual trajectories is small compared with the radius of the earth, these trajectories are therefore approximated by parabolas, i.e., gravity is assumed constant both in magnitude and direction over the entire trajectory. Thus, the motion of the vehicle can be described in closed form. The coordinate system employed is that shown in Figure 3.1. The origin lies at Johnston Island, and the x, y, z axes point to the east, north and vertical, respectively. The trajectories are assumed to lie in a vertical plane, containing the z axis, and each is assumed to have a constant azimuth, α, measured east of north. The following quantities are computed, as a function of time, by the subroutine: x, y, z; $\dot{x}$, $\dot{y}$, $\dot{z}$; $\dot{x}/V$, $\dot{y}/V$, $\dot{z}/V$; H, E_r. Here, V is the velocity of the vehicle, H is the altitude of the vehicle above the surface of the (curved) earth, and E_r is the earth range of the vehicle. These quantities are given as follows:

$$x = \rho \sin\alpha, \; y = \rho \cos\alpha, \; z = z_o + \Delta t(\dot{z}_o - \frac{1}{2}g\Delta t)$$

$$\dot{x} = (\ddot{\rho}_o\Delta t+\dot{\rho}_o)\sin\alpha, \; y = (\ddot{\rho}_o\Delta t+\dot{\rho}_o)\cos\alpha, \; \dot{z} = \dot{z}_o - g\Delta t$$

$$V = (\dot{x}^2+\dot{y}^2+\dot{z}^2)^{1/2}, \; E_r = R \tan^{-1} \frac{\rho}{R+z}$$

$$H = \frac{\rho^2+z^2+2zR}{[\rho^2 + (z+R)^2]^{1/2} + R}$$

where,

$$\rho = (x^2+y^2)^{1/2} = \rho_o+\Delta t(\dot{\rho}_o+\frac{1}{2}\ddot{\rho}_o\Delta t)$$

$$\Delta t = t - t_o$$

R = equatorial radius of the earth = 6371.2 km

y = 9.80 meters/sec^2

The time, t_o, denotes the instant that the trajectory computation begins. Table 3.1 shows the values of α, t_o, z_o, $\dot{z}_o$, ρ_o, $\dot{\rho}_o$ employed in the TRAJ subroutine for Rockets 8, 9, 15, 19, and 26.

GLOSSARY OF TERMS

Fortran Name	Formula Name	Description and Physical Units
ALPHA	α	angle (radians) between position vector and Y-axis (Y-axis is assumed to point north)
DCVX	$\cos V_x$	cosine (dimensionless) of angle between velocity vectors and X-axis
DCVY	$\cos V_y$	cosine (dimensionless) of angle between velocity vector and Y-axis
DCVZ	$\cos V_z$	cosine (dimensionless) of angle between velocity vector and Z-axis
ER	earth range	range of vehicle (kilometers)
G	g	gravitational acceleration (kilometers/second/second)
H	H	altitude of vehicle (kilometers)
R	R	radius of the earth (kilometers)
RHO	ρ	current value of horizontal position vector (kilometers)
RHOI	ρ_o	initial value of horizontal position vector (kilometers)
RHOVI	$\dot{\rho}_o$	initial value of horizontal velocity vector (kilometers/sec)
RODDT	$\ddot{\rho}_o$	initial value of acceleration along horizontal (kilometers/sec^2)
T	t	current value of time (seconds)
TI	t_o	initial value of time (seconds)
X	X	current value of X-coordinate of position vector (kilometers)
XV	$\dot{X}$	current value of X-coordinate of velocity vector (kilometers/second)
Y	Y	current value of Y-coordinate of position vector (kilometers)
YV	$\dot{Y}$	current value of Y-coordinate of velocity vector (kilometers/second)

GLOSSARY OF TERMS (contd.)

Fortran Name	Formula Name	Description and Physical Units
Z	z	current value of Z-coordinate of position vector (kilometers)
ZV	$\dot{z}$	current value of Z-coordinate of velocity vectors (kilometers/second)
ZI	z_o	initial value of Z-coordinate of position vector (kilometers)
ZVI	$\dot{z}_o$	initial value of Z-coordinate of velocity vector (kilometers/second)

3.3.4 Subroutine MAGNET. The primary purpose of the MAGNET subroutine is to generate theoretical east, north, and vertical componen estimates of the earth's magnetic field.

The main field potential is approximated by a truncated expansion of a series of associated Legendre polynomials

$$V = a\sum_{n=1}^{7} \sum_{m=1}^{n} \frac{a}{r}^{n} P^{m,n}(\mu) \{F(n,m) \cos(m-1) \phi + G(n,m) \sin(m-1) \phi\}$$

where:

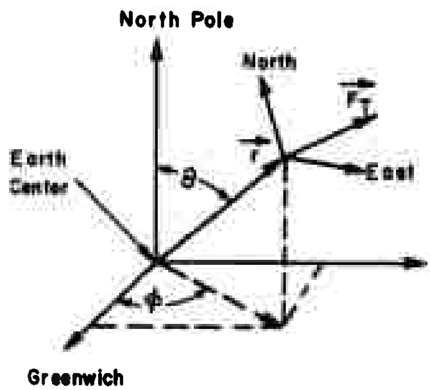
a = earth radius

r = distance from earth center

ϕ = geographic longitude (east)

$\mu = \cos\theta$, θ = geographic colatitude

$P^{m,n}$ = associated Legendre polynomials



The gradient of V represents the magnetic field intensity vector. In spherical coordinates at the point (r, θ, ϕ) the gradient is given as

$$F_T = \nabla\vec{V} = \frac{1}{r\ \sin\theta}\frac{\partial V}{\partial \phi}\,\bar{i} - \frac{1}{r}\frac{\partial V}{\partial \theta}\,\bar{j} + \frac{\partial V}{\partial r}\,\bar{k}$$

where $\bar{i}$, $\bar{j}$, and $\bar{k}$ are the east, north, and vertical unit vectors as described previously.

$$BR = \frac{\partial V}{\partial r} = -\sum_{n=1}^{7} n \sum_{m=1}^{n} \left(\frac{a}{r}\right)^{n+1} P^{m,n}(\mu) \left\{F(n,m)\ \cos(m-1)\phi \right.$$

$$\left. + \ G(n,m)\ \sin(m-1)\phi\right\}$$

$$B\theta = \frac{1}{r}\frac{\partial V}{\partial \theta} = \sum_{n=1}^{7} \sum_{m=1}^{n} \left(\frac{a}{r}\right)^{n+1} \left[\frac{d(P^{m,n}(\mu)\ )}{d\mu}\right] \left\{F(n,m)\ \cos(m-1)\phi \right.$$

$$\left. + \ G(n,m)\ \sin(m-1)\phi\right\}$$

$$B\phi = \frac{1}{r\,\sin\theta}\,\frac{\partial V}{\partial \phi} = \sum_{n=1}^{7} \sum_{m=1}^{n} \frac{a}{r}^{n+1} P^{m,n}(\mu)(m-1) \left\{ -F(n,m)\,\sin(m-1)\phi \right.$$

$$\left. +\, Gd(n,m)\,\cos(m-1)\phi \right\} \frac{1}{\sin\theta}$$

where:

$$P^{m,n}(\mu) = \cos\theta\, P^{m,n-1} - P^{m,n-2}\, C(n,m)$$

$$\frac{dP^{m,n}}{d\mu}(\mu) = \cos\theta\, \frac{dP^{m,n}}{d\mu} - \sin\theta\, P^{m,n-1} - \frac{dP^{m,n-2}}{d\mu}\, C(n,m)$$

$$P^{m,n}(\mu) = \left\{ \frac{0,\ m > n}{1,\ m=n=1} \right\}$$

and $\quad C(n,m) = (n-2)^2 - (m-1)^2/(2n-3)(2n-5)$

$$C(n,m) = 0,\ m > n$$

also

$$P^{m,n}(\mu) = \sin\theta\, P^{m-1,n-1}(\mu)$$

$$\frac{dP^{m,n}(\mu)}{d\mu} = \cos\theta\, P^{m-1,n-1}(\mu) + \sin\theta\, \frac{dP^{m-1,n-1}(\mu)}{d\mu}$$

The constants F(n,m) and G(n,m) were obtained from Reference 4 and can be described as arrays as follows:

$$G(n,m) = \begin{bmatrix} 0.0 & & & & & & \\ 0.0 & -5798.9 & & & & & \\ 0.0 & 3312.4 & -157.9 & & & & \\ 0.0 & 1487.0 & -407.5 & 21.0 & & & \\ 0.0 & -1182.5 & 1000.6 & 43.0 & 138.5 & & \\ 0.0 & -79.6 & -200.0 & 459.7 & 242.1 & -121.8 & \\ 0.0 & -575.8 & -873.5 & -340.6 & -11.8 & -111.6 & -32.5 \end{bmatrix}$$

$$F(n,m) = \begin{bmatrix} 0.0 & & & & & & \\ 30411.2 & 2147.4 & & & & & \\ 2403.5 & -5125.3 & -1338.[illegible] & & & & \\ -3151.8 & 6213.0 & -2489.8 & -649.6 & & & \\ -4179.4 & -4529.8 & -2179.5 & 700.8 & -204.4 & & \\ 1625.6 & -3440.7 & -1944.7 & -60.8 & 277.5 & 69.7 & \\ -1952.3 & -485.3 & 321.2 & 2141.3 & 105.1 & 22.7 & 111.5 \end{bmatrix}$$

The direction cosines of the magnetic vector then become

$$\cos(F,X) = \sqrt{\frac{BR}{BR^2+B\theta^2+B\phi^2}}\ , \quad \cos(F,Y) = \sqrt{\frac{B\theta}{BR^2+B\theta^2+B\phi^2}}$$

$$\cos(F,Z) = \sqrt{\frac{B\phi}{BR^2+B\theta^2+B\phi^2}}$$

GLOSSARY OF TERMS—MAGNET SUBROUTINE

Fortran Name	Formula Name	Description
THETA	Θ	geographic colatitude in radians
PHI	ϕ	geographic longitude in radians
R	γ	distance from earth's center in kilometers
C	$\mu, \cos\Theta$	
S	$\sin\Theta$	
SP(M)	$\sin(m\phi)$	
AOR(I)	$(a/r)^I$	
BR	BR	radial component of magnetic field (gauss)
BTHETA	$B\Theta$	northward component of magnetic field (gauss)
BPHI	$B\phi$	eastward component of magnetic field (gauss)
P(M,N)	$P^{m,n}$	associated Legendre polynomials
DP(M,N)	$dP^{m,n}/d\mu$	
H		altitude in kilometers

3.3.5 Subroutine CONE. This routine is written in Fortran II and is used for all rockets.

The routine determines for a given time the half-cone angle GAMMA and the coning azimuthal angle in the coning axis coordinate system BCONE.

For nonconing payloads the routine takes the form of a dummy subroutine which returns zero for BCONE and GAMMA.

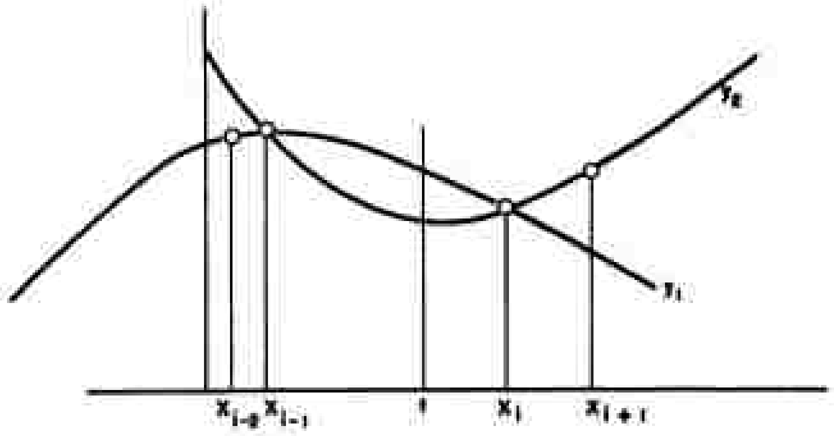
For coning payloads an empirically determined coning buildup table for GAMMA and BCONE as a function of time is initialized at the

beginning of the routine. During execution of the program, a double-weighted parabolic interpolation is used to determine the values of GAMMA and BCONE. If the given time is less than the first entry in the table, then this would correspond to nonconing time, and zero is returned for both values.

During coning buildup, when the given time falls in the range of the table, a single parabolic interpolation is used at the end points, and a double-weighted parabolic interpolation is used in the subrange which consists of the points between the second and second-to-last points in the table.

For values of time during uniform coning, i.e., when the given time is greater than the last entry in the table, a constant GAMMA is returned while the value of BCONE is computed using a sawtooth function.

This routine uses a function subprogram called FCN which performs the actual interpolation using a Lagrangian interpolating polynomial. The figure below is a pictorial description of the general case with the corresponding formulas where t is the argument value of time.



$$y(t) = \frac{(X_i - t)\,y_1(t) + (t - X_{i-1})\,y_2(t)}{(X_i - X_{i-1})}$$

GLOSSARY OF TERMS

Fortran Name	Description
N	number of points in the table
T	systems time
ISW_1	used as a switch and is equal to one the first time the subroutine is called and two every other time
X1(I)	the independent variable in GAMMA table (systems time)
X2(I)	the independent variable in the BCONE table (systems time)
Y1(I)	the dependent variable in the GAMMA table (degrees)
Y2(I)	the dependent variable in the BCONE table
PI	π
DT	$2\pi/f$; the spin period
TU	time at which uniform coning begins (systems time)
GAMMA	the half-cone angle
BCONE	the coning azimuthal angle in the coning axis coordinate system

3.3.6 Function ATAN1. This routine is written in Fortran II and is a standard two-argument arctangent routine. The subprogram calculates the arctangent of y over x and determines the angle in radians between $-\pi$ and π, i.e.,

$$-\pi < \tan^{-1} \frac{y}{x} \le \pi$$

The calling sequence is:

ATAN1 (y,x)

It is important to note that the arctangent of the first argument divided by the second argument is computed.

Figure 3.2 illustrates a general case in the second quadrant and the angle θ the program computes.

The routine is used differently in two places in the main program. The first time it is used to compute the longitude ϕ of the payload using the x, y, and z position in geocentric coordinates (Figure 3.3). This angle is determined using the normal calling sequence. The

second time the routine is called it is used to determine the azimuth of the rocket axis. At this time the calling sequence is reversed and the routine computes ATAN1 (x,y) (Figure 3.4).

$$\psi_i = \tan^{-1} \frac{x}{y}$$

By this reversal in the calling sequence we are able to compute both angles with one routine.

3.3.7 Function FCN. This function subprogram evaluates the second-degree Lagrangian interpolating polynomial,

$$f(x) = \frac{(x-x_2)(x-x_3)}{(x_1-x_2)(x_1-x_3)} y_1 + \frac{(x-x_1)(x-x_3)}{(x_2-x_1)(x_2-x_3)} y_2 + \frac{(x-x_1)(x-x_2)}{(x_3-x_1)(x_3-x_2)} y_3$$

which is equivalent to a parabola of the form,

$$f(x) = Ax^2 + Bx + C$$

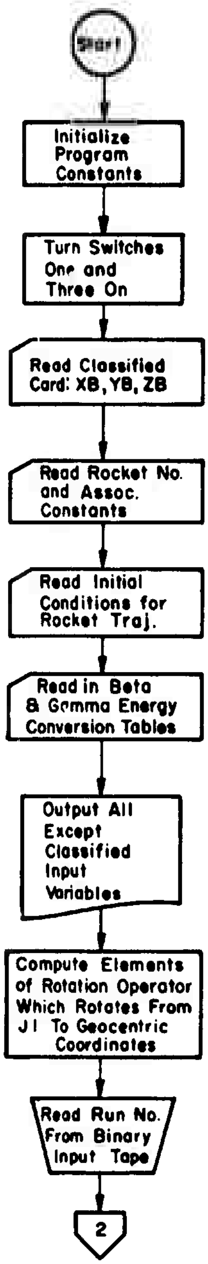
through the points $\{(x_1,y_1), (x_2,y_2), (x_3,y_3)\}$.

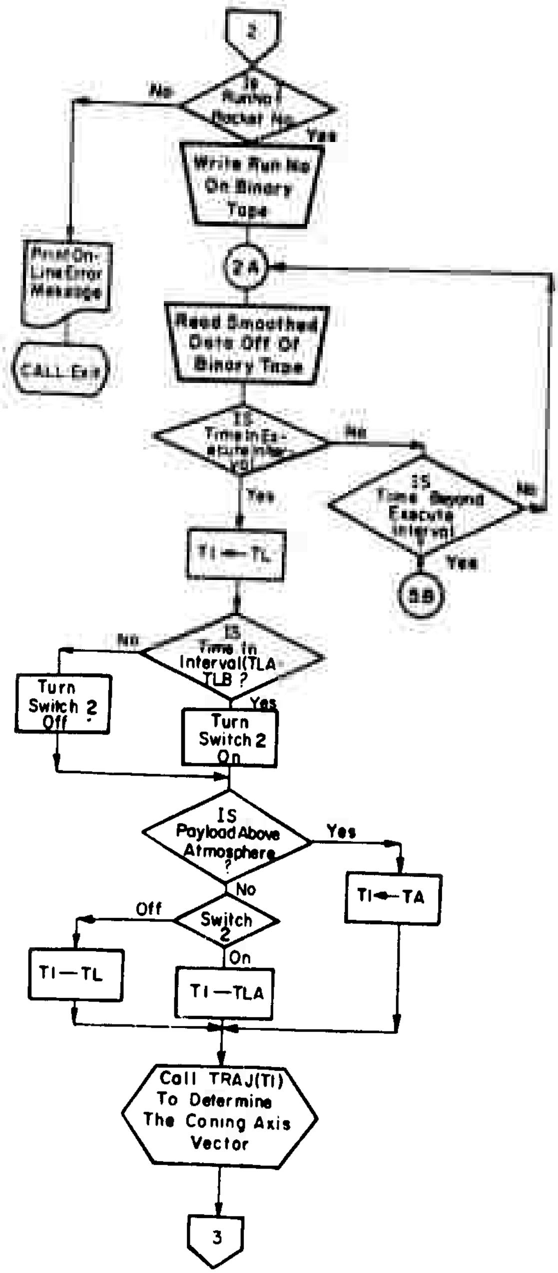
The routine is written in Fortran II and is used by the CONE subroutine to do the actual parabolic interpolation. The calling sequence is

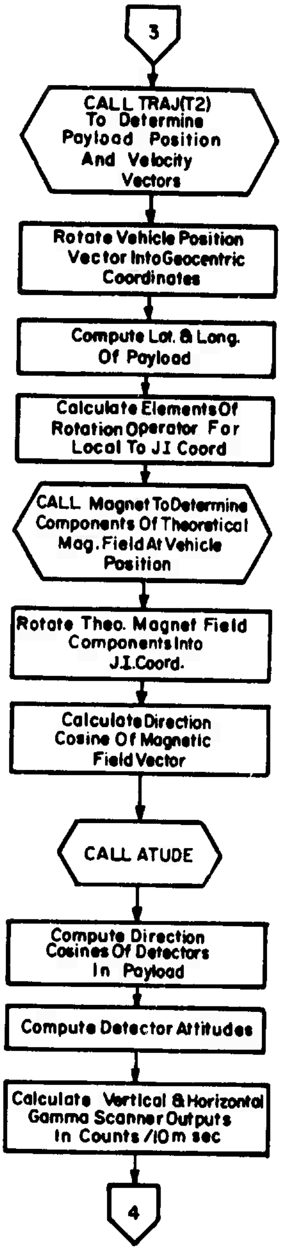
FCN(xP,x,y,I)

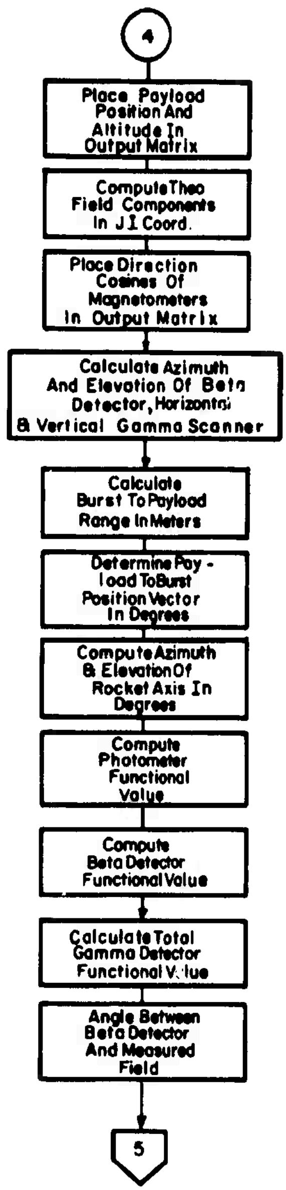
where xP is the independent variable for which the corresponding ordinate is desired, x and y are arrays of the tabulated function, x the independent variable, and y the dependent variable. The argument I is the subscript of the first point to be used from the tabulated function.

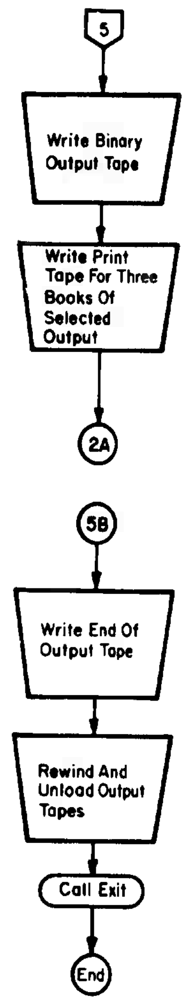
3.3.8 Flow Diagrams. The following diagrams outline the logical and computational processes for each of the routines discussed above and are followed by the program coding as stated in Fortran and preceded by a glossary of terms for the convenience of the reader.

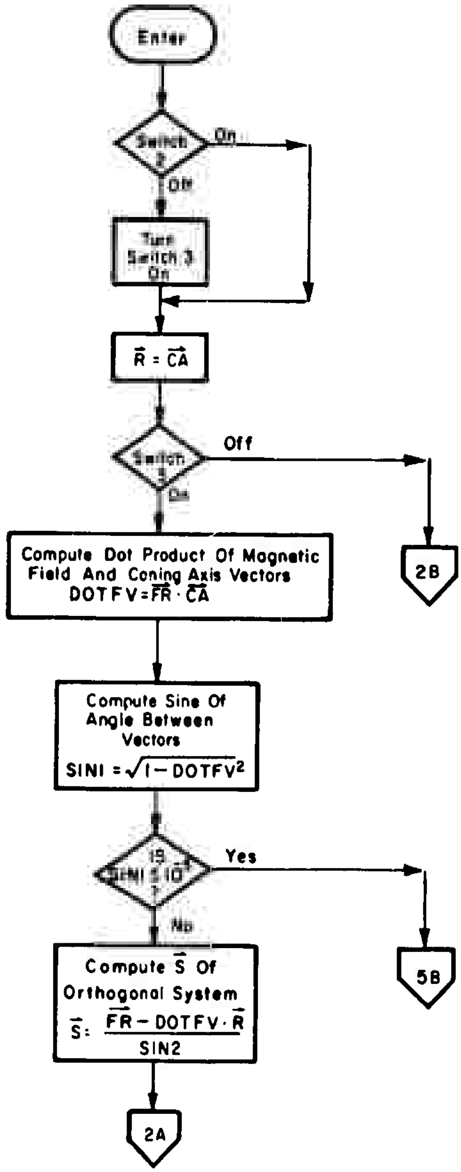

Start
Initialize Program Constants
Turn Switches One and Three On
Read Classified Card: XB, YB, ZB
Read Rocket No. and Assoc. Constants
Read Initial Conditions for Rocket Traj.
Read in Beta & Gamma Energy Conversion Tables
Output All Except Classified Input Variables
Compute Elements of Rotation Operator Which Rotates From J I To Geocentric Coordinates
Read Run No. From Binary Input Tape
2


2
No
Yes
Write Run No On Binary Tape
Print On-Line Error Message
CALL Exit
2 A
Read Smoothed Data Off Of Binary Tape
No
Yes
Is Time Beyond Execute Interval
No
Yes
5B
No
Is Time In Interval(TLA-TLB ?
Yes
Turn Switch 2 Off
Turn Switch 2 On
IS Payload Above Atmosphere ?
Yes
No
TI←TA
Off
Switch 2
On
TI—TL
TI—TLA
Call TRAJ(TI) To Determine The Coning Axis Vector
3

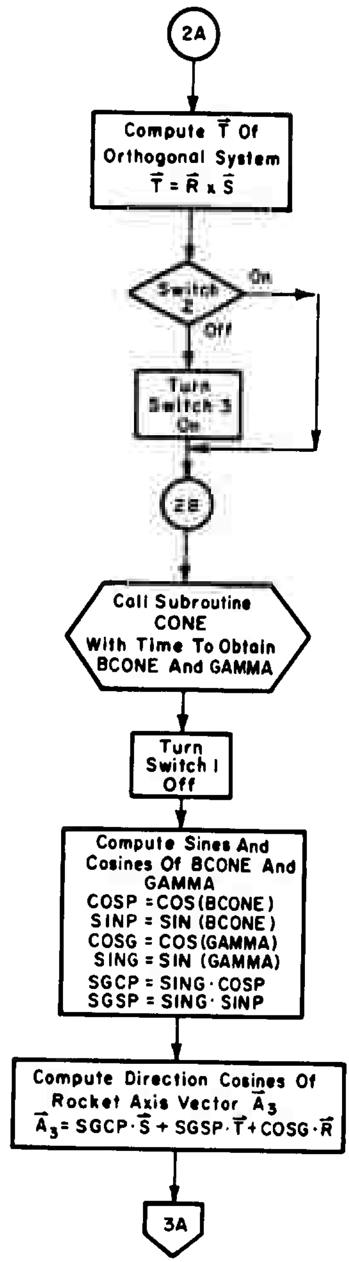

3
CALL TRAJ(T2) To Determine Payload Position And Velocity Vectors
Rotate Vehicle Position Vector Into Geocentric Coordinates
Compute Lat. & Long. Of Payload
Calculate Elements Of Rotation Operator For Local To JI Coord
CALL Magnet To Determine Components Of Theoretical Mag. Field At Vehicle Position
Rotate Theo. Magnet Field Components Into J.I. Coord.
Calculate Direction Cosine Of Magnetic Field Vector
CALL ATUDE
Compute Direction Cosines Of Detectors In Payload
Compute Detector Attitudes
Calculate Vertical & Horizontal Gamma Scanner Outputs In Counts /10 m sec
4

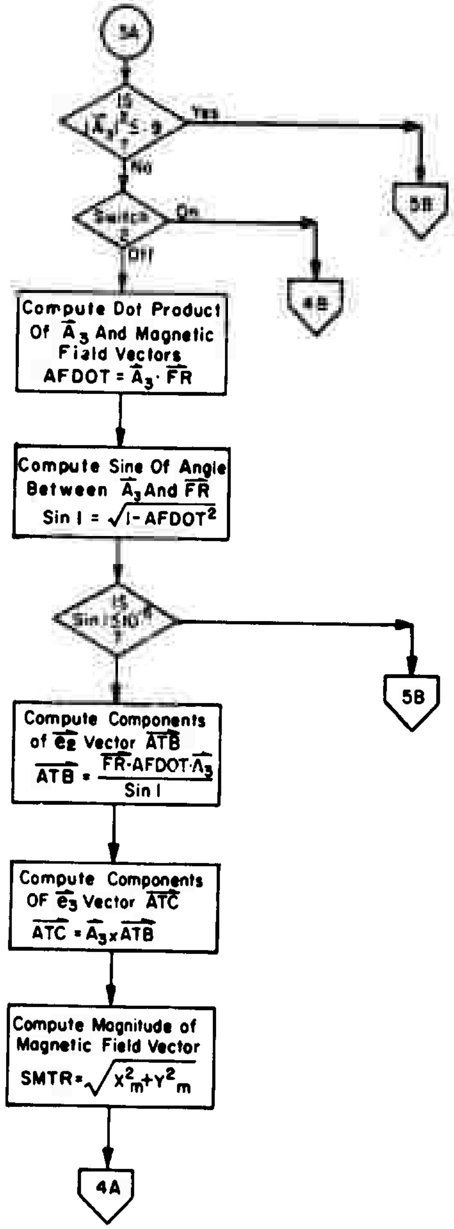

4
Place Payload Position And Altitude In Output Matrix
Compute Theo Field Components In J1 Coord.
Place Direction Cosines Of Magnetometers In Output Matrix
Calculate Azimuth And Elevation Of Beta Detector, Horizontal & Vertical Gamma Scanner
Calculate Burst To Payload Range In Meters
Determine Pay-load To Burst Position Vector In Degrees
Compute Azimuth & Elevation Of Rocket Axis In Degrees
Compute Photometer Functional Value
Compute Beta Detector Functional Value
Calculate Total Gamma Detector Functional Value
Angle Between Beta Detector And Measured Field
5


5
Write Binary Output Tape
Write Print Tape For Three Books Of Selected Output
2A
5B
Write End Of Output Tape
Rewind And Unload Output Tapes
Call Exit
End

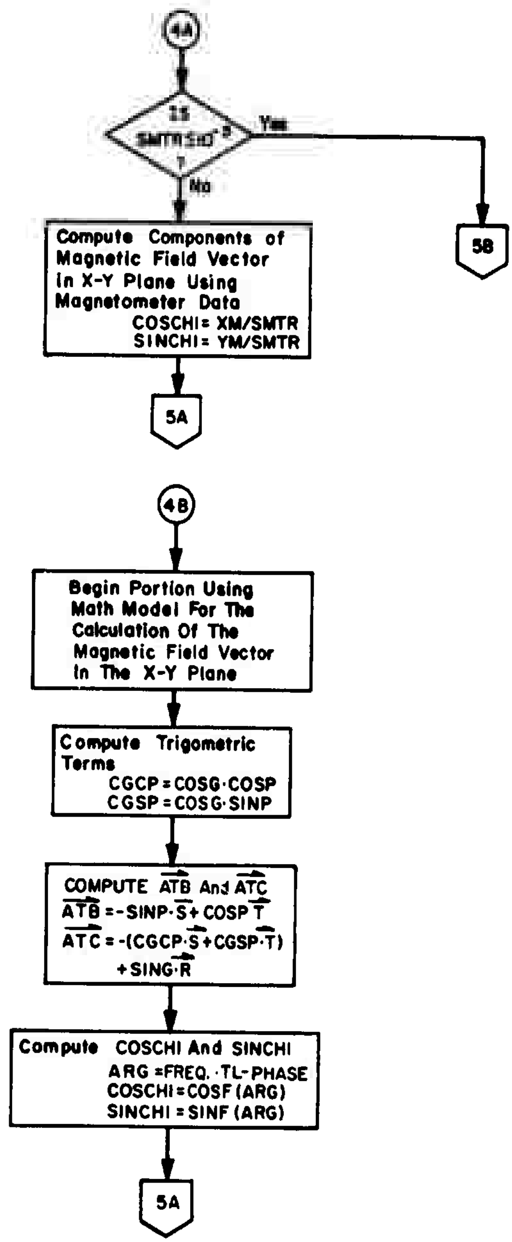


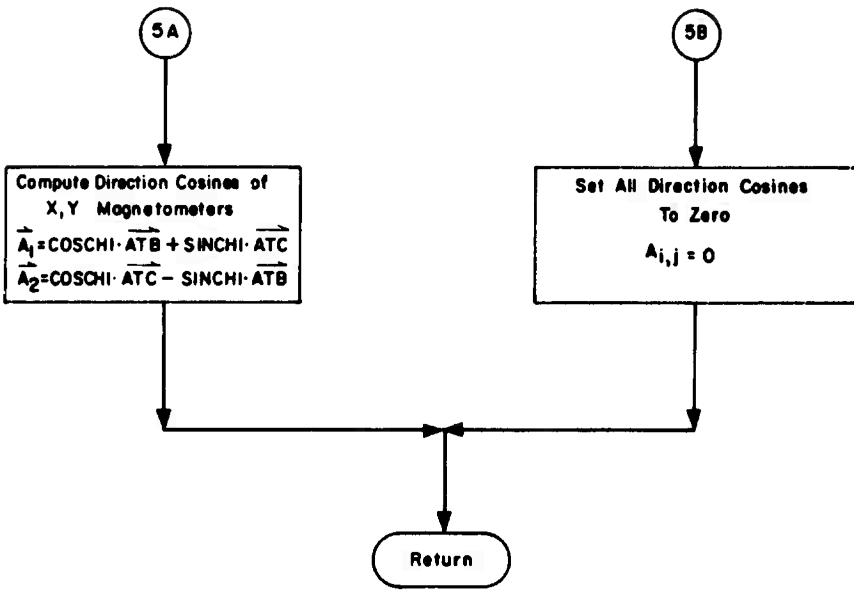
Enter
Switch 2
On
Off
Turn Switch 3 On
R = CA
Switch 3
Off
On
Compute Dot Product Of Magnetic Field And Coning Axis Vectors
DOTFV = FR · CA
2B
Compute Sine Of Angle Between Vectors
SINI = √(1 − DOTFV²)
Yes
No
Compute S Of Orthogonal System
S: (FR − DOTFV · R) / SIN2
5B
2A

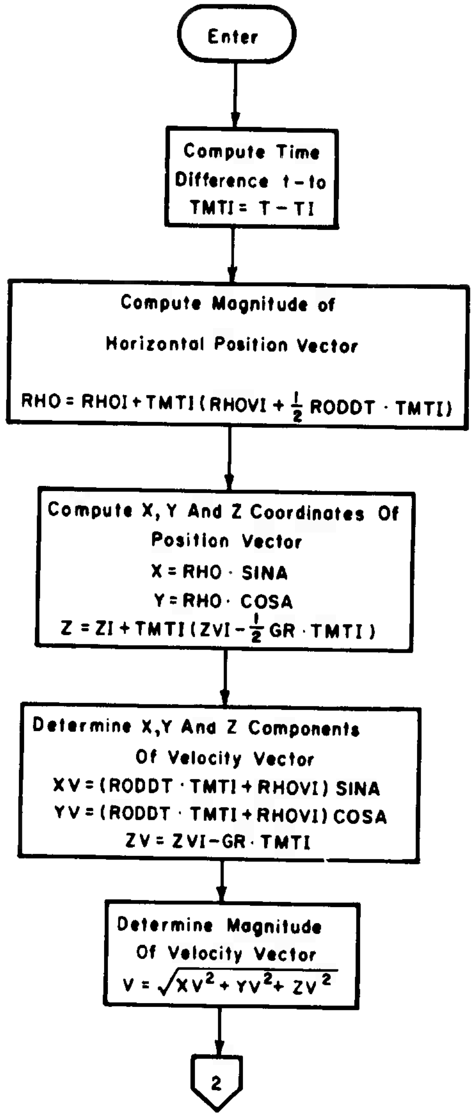

2A
Compute $\vec{T}$ Of Orthogonal System
$\vec{T} = \vec{R} \times \vec{S}$
Switch 2
On
Off
Turn Switch 3 On
2B
Call Subroutine CONE With Time To Obtain BCONE And GAMMA
Turn Switch 1 Off
Compute Sines And Cosines Of BCONE And GAMMA
COSP = COS(BCONE)
SINP = SIN (BCONE)
COSG = COS(GAMMA)
SING = SIN (GAMMA)
SGCP = SING · COSP
SGSP = SING · SINP
Compute Direction Cosines Of Rocket Axis Vector $\vec{A}_3$
$\vec{A}_3$ = SGCP · $\vec{S}$ + SGSP · $\vec{T}$ + COSG · $\vec{R}$
3A

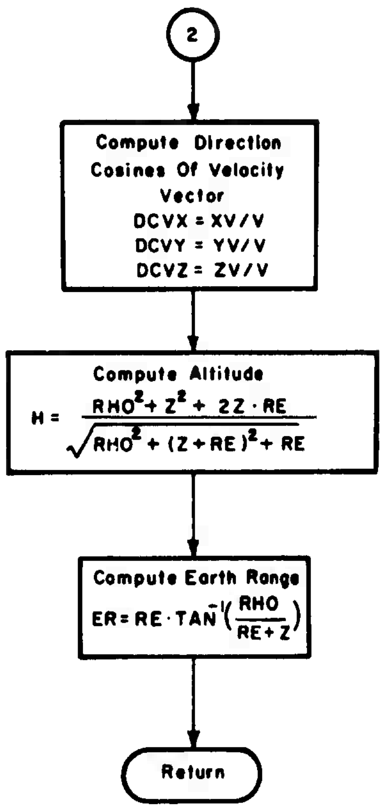


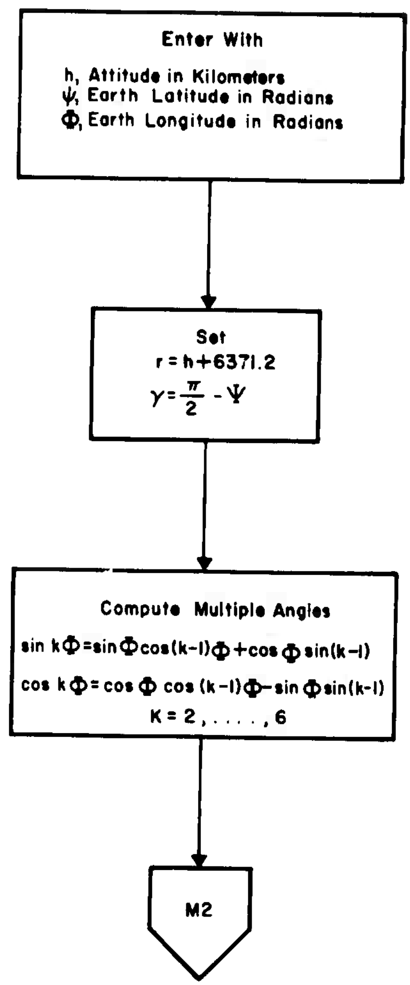
3A
Is
Yes
No
5B
Switch
On
Off
4B
Compute Dot Product Of $\hat{A}_3$ And Magnetic Field Vectors
AFDOT = $\hat{A}_3 \cdot \overrightarrow{FR}$
Compute Sine Of Angle Between $\hat{A}_3$ And $\overrightarrow{FR}$
Sin I = $\sqrt{1 - AFDOT^2}$
Is
5B
Compute Components of $\overrightarrow{e_2}$ Vector $\overrightarrow{ATB}$
$\overrightarrow{ATB} = \frac{\overrightarrow{FR} - AFDOT \cdot \hat{A}_3}{\text{Sin I}}$
Compute Components OF $\overrightarrow{e_3}$ Vector $\overrightarrow{ATC}$
$\overrightarrow{ATC} = \hat{A}_3 \times \overrightarrow{ATB}$
Compute Magnitude of Magnetic Field Vector
SMTR = $\sqrt{X_m^2 + Y_m^2}$
4A


4A
Yes
No
Compute Components of Magnetic Field Vector in X-Y Plane Using Magnetometer Data
COSCHI = XM/SMTR
SINCHI = YM/SMTR
5B
5A
4B
Begin Portion Using Math Model For The Calculation Of The Magnetic Field Vector In The X-Y Plane
Compute Trigometric Terms
CGCP = COSG·COSP
CGSP = COSG·SINP
COMPUTE ATB And ATC
ATB = -SINP·S + COSP T
ATC = -(CGCP·S + CGSP·T)
+ SING·R
Compute COSCHI And SINCHI
ARG = FREQ.·TL-PHASE
COSCHI = COSF (ARG)
SINCHI = SINF (ARG)
5A


5A
Compute Direction Cosines of X, Y Magnetometers
$\vec{A_1}$ = COSCHI · $\vec{ATB}$ + SINCHI · $\vec{ATC}$
$\vec{A_2}$ = COSCHI · $\vec{ATC}$ − SINCHI · $\vec{ATB}$
5B
Set All Direction Cosines To Zero
$A_{i,j} = 0$
Return


Enter
Compute Time
Difference t − to
TMTI = T − TI
Compute Magnitude of
Horizontal Position Vector
RHO = RHOI + TMTI (RHOVI + 1/2 RODDT · TMTI)
Compute X, Y And Z Coordinates Of
Position Vector
X = RHO · SINA
Y = RHO · COSA
Z = ZI + TMTI (ZVI − 1/2 GR · TMTI)
Determine X,Y And Z Components
Of Velocity Vector
XV = (RODDT · TMTI + RHOVI) SINA
YV = (RODDT · TMTI + RHOVI) COSA
ZV = ZVI − GR · TMTI
Determine Magnitude
Of Velocity Vector
V = √(XV² + YV² + ZV²)
2


2
Compute Direction Cosines Of Velocity Vector
DCVX = XV/V
DCVY = YV/V
DCVZ = ZV/V
Compute Altitude
$H = \frac{RHO^2 + Z^2 + 2Z \cdot RE}{\sqrt{RHO^2 + (Z + RE)^2} + RE}$
Compute Earth Range
$ER = RE \cdot TAN^{-1}\left(\frac{RHO}{RE + Z}\right)$
Return


Enter With
h, Attitude in Kilometers
ψ, Earth Latitude in Radians
Φ, Earth Longitude in Radians
Set
r = h+6371.2
$\gamma = \frac{\pi}{2} - \Psi$
Compute Multiple Angles
sin kΦ=sinΦcos(k-1)Φ+cos Φ sin(k-1)
cos kΦ= cos Φ cos (k-1)Φ-sin Φsin(k-1)
K = 2, ... , 6
M2

M 2

Setup Initial Values
For BR, BTHETA, PHI Which
Represents The Three Components
After Accumulations

$$BR = \frac{a}{r} F(1,1) + 2\left(\frac{a}{r}\right)^3 \left[P(2,1)TS1 + P(2,2)TS2\right]$$

$$BTHETA = -\left(\frac{a}{r}\right)^3 \left[DP(2,1)\ TS1 + DP(2,2)\ TS2\right]$$

$$BPHI = -\left(\frac{a}{r}\right)^3 P(2,2) \left[-F(2,2) \sin\phi + G(2,2) \cos\phi\right]$$

a, Earth Radius

$P(1,1) = 1.0$ $\qquad DP(2,1) = -\sin.\theta$

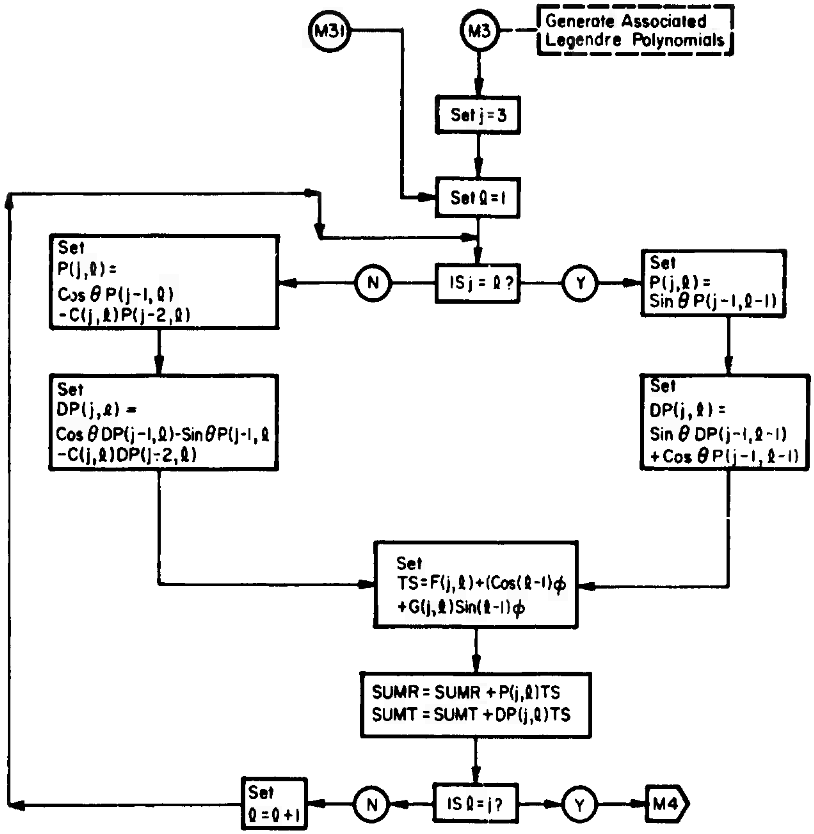
$P(2,1) = \cos.\theta$ $\qquad DP(2,2) = \cos C$

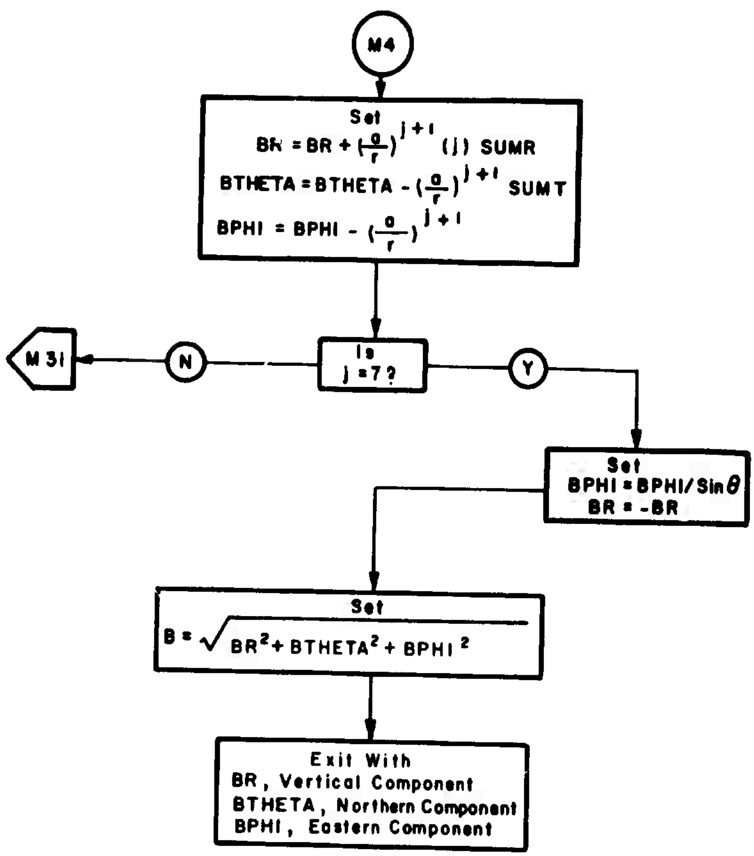
$P(2,2) = \sin.\theta$

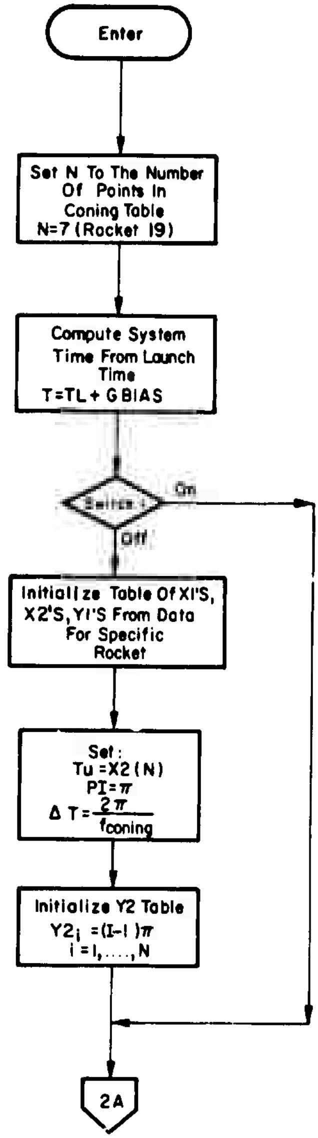
$TS1 = F(2,1)$

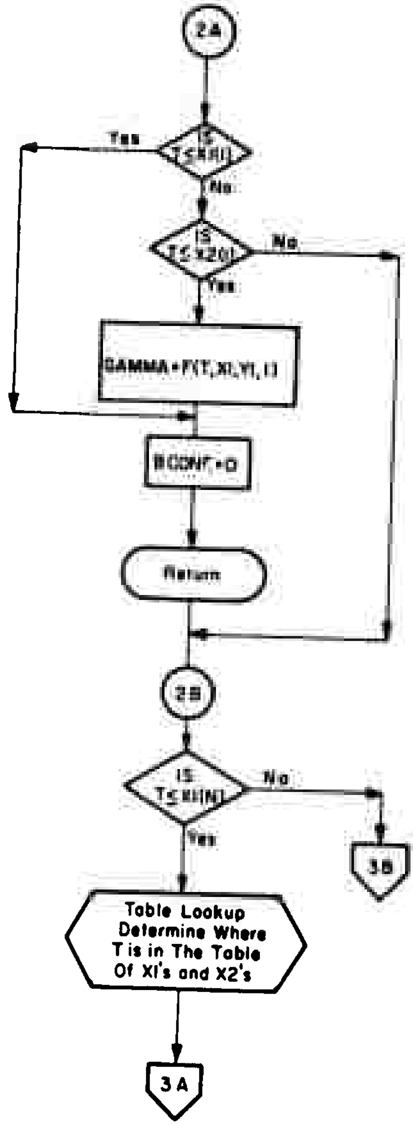
$TS2 = F(2,2) \cos\phi + G(2,2) \sin\phi$

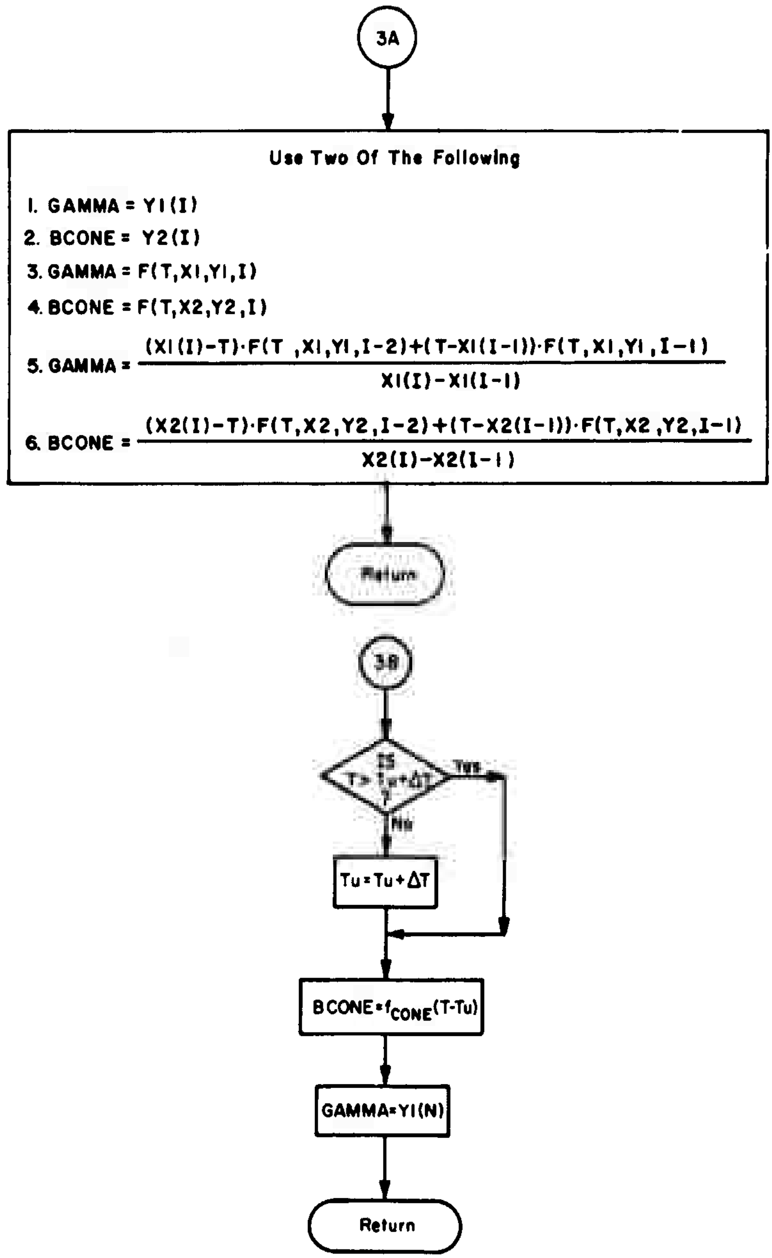
M 3

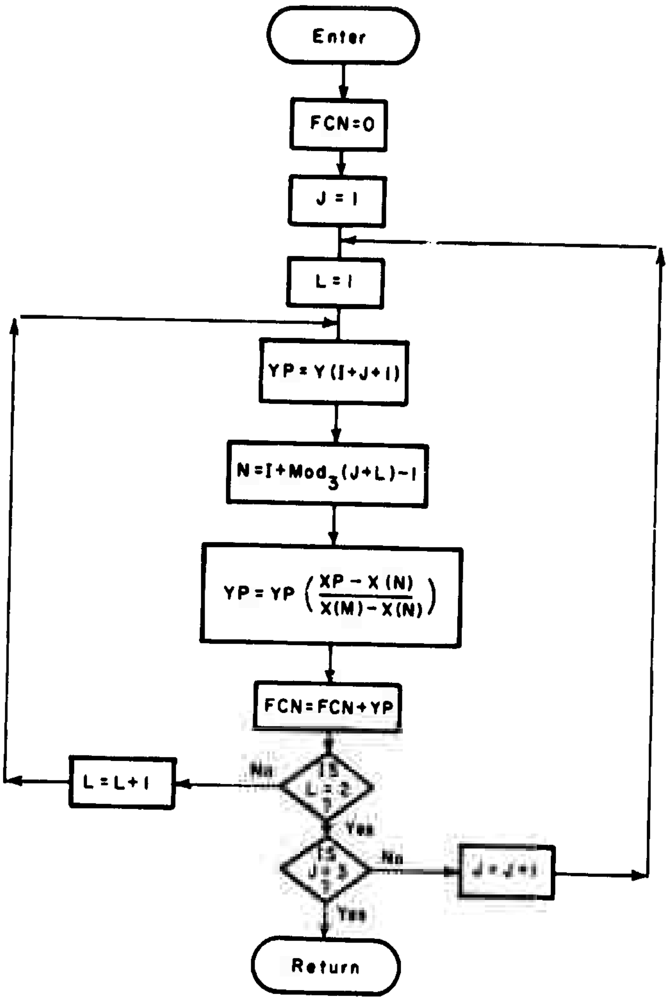

M31
M3
Generate Associated Legendre Polynomials
Set j = 3
Set ℓ = 1
IS j = ℓ ?
N
Y
Set P(j,ℓ) = Cos θ P(j-1,ℓ) -C(j,ℓ)P(j-2,ℓ)
Set P(j,ℓ) = Sin θ P(j-1,ℓ-1)
Set DP(j,ℓ) = Cos θ DP(j-1,ℓ)-Sin θ P(j-1,ℓ -C(j,ℓ)DP(j-2,ℓ)
Set DP(j,ℓ) = Sin θ DP(j-1,ℓ-1) +Cos θ P(j-1,ℓ-1)
Set TS=F(j,ℓ)+(Cos(ℓ-1)φ +G(j,ℓ)Sin(ℓ-1)φ
SUMR = SUMR + P(j,ℓ)TS
SUMT = SUMT + DP(j,ℓ)TS
IS ℓ = j ?
N
Y
M4
Set ℓ = ℓ + 1

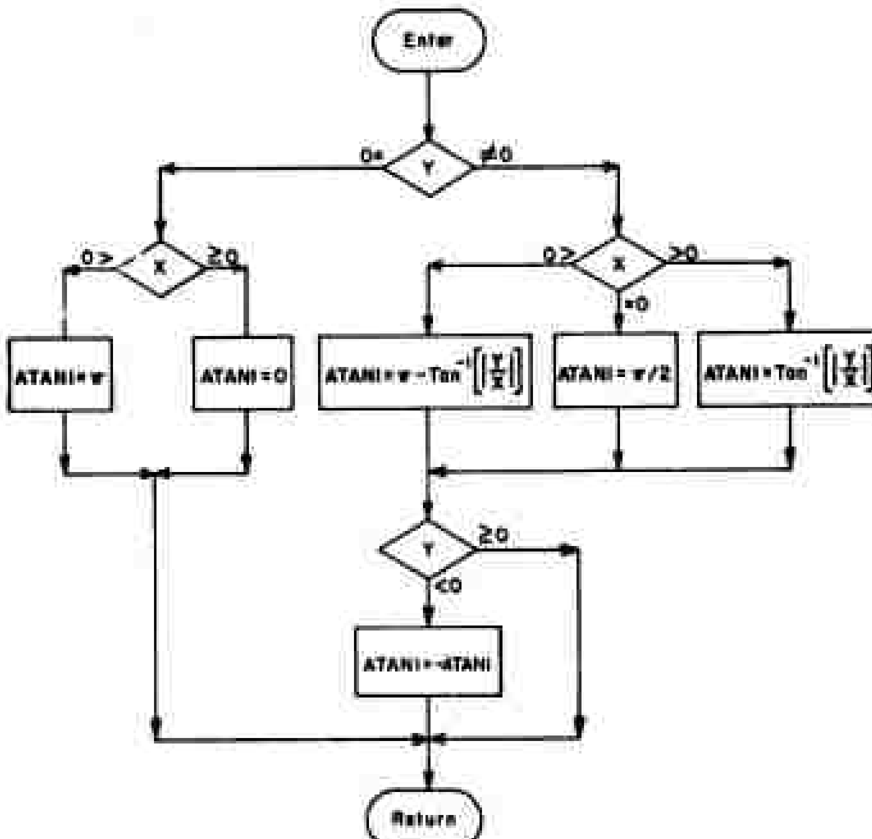

M4
Set
BR = BR + (a/r)^{j+1} (j) SUMR
BTHETA = BTHETA - (a/r)^{j+1} SUMT
BPHI = BPHI - (a/r)^{j+1}
Is
j = 7 ?
N
M 31
Y
Set
BPHI = BPHI/Sin θ
BR = -BR
Set
B = √(BR² + BTHETA² + BPHI²)
Exit With
BR , Vertical Component
BTHETA , Northern Component
BPHI , Eastern Component


Enter
Set N To The Number Of Points In Coning Table
N=7 (Rocket 19)
Compute System Time From Launch Time
T=TL+GBIAS
Switch 1
On
Off
Initialize Table Of X1'S, X2'S, Y1'S From Data For Specific Rocket
Set:
Tu =X2(N)
PI=π
ΔT=2π/f_coning
Initialize Y2 Table
Y2_i =(I-1)π
i =1,....,N
2A


2A
Yes
IS
No
IS
No
Yes
GAMMA = F(T, XI, YI, I)
BCONF = 0
Return
2B
IS
T ≤ XI(N)
No
Yes
3B
Table Lookup
Determine Where
T is in The Table
Of XI's and X2's
3A


3A
Use Two Of The Following
1. GAMMA = Y1(I)
2. BCONE = Y2(I)
3. GAMMA = F(T,X1,Y1,I)
4. BCONE = F(T,X2,Y2,I)
5. GAMMA = (X1(I)-T)·F(T ,X1,Y1,I-2)+(T-X1(I-1))·F(T,X1,Y1,I-1) / X1(I)-X1(I-1)
6. BCONE = (X2(I)-T)·F(T,X2,Y2,I-2)+(T-X2(I-1))·F(T,X2,Y2,I-1) / X2(I)-X2(I-1)
3B
Yes
No
Tu=Tu+ΔT
BCONE=fCONE(T-Tu)
GAMMA=Y1(N)
Return


Enter
FCN=0
J = 1
L = 1
YP = Y(I+J+1)
N=I+Mod$_3$(J+L)-1
YP = YP $\left(\frac{XP - X(N)}{X(M) - X(N)}\right)$
FCN=FCN+YP
No
L=L+1
Yes
No
Yes
Return



Enter
Y
0=
≠0
X
0>
≥0
X
0>
>0
=0
ATANI=π
ATANI=0
ATANI=π-Tan⁻¹[|Y/X|]
ATANI=π/2
ATANI=Tan⁻¹[|Y/X|]
Y
≥0
<0
ATANI=-ATANI
Return

GLOSSARY OF TERMS

Fortran Name	Formula Name	Description
RAD		$180/\pi$
TPI		2π
FLAT		launch latitude (degrees)
FLONG		launch longitude (degrees)
F(I,J)		constants for Legendre polynomials
G(I,J)		constants for Legendre polynomials
THETA(I)		detector elevation angles (degrees)
PHI(I)		detector azimuth angles (degrees)
STHETA(I)		sine of THETA(I)
CTHETA(I)		cosine of THETA(I)
SPHI(I)		sine of PHI(I)
CPHI(I)		cosine of PHI(I)
TRIG1(I)		CTHETA(I) · SPHI(I)
TRIG2(I)		CTHETA(I) · CPHI(I)
BIAS		burst time in systems time
XB		x-coordinate of burst in J I
YB		y-coordinate of burst in J I
ZB		z-coordinate of burst in J I
NROCKT		rocket number
TSTART		processing start time
TSTOP		processing stop time
GBIAS		launch time in systems time
POTMET		photometer multiplying factor
TLA		mathematical model start time in L.T.
TLB		mathematical model stop time in L.T.
FREQ		spin frequency

GLOSSARY OF TERMS (contd.)

Fortran Name	Formula Name	Description
PHASE		spin phase angle
TA		atmosphere exit time
ALPHR		azimuth of rocket trajectory (degrees)
GR		acc. of gravity
RHOI		initial ground distance
RHOVI		initial ground rate
RODDT		initial horizontal rocket acceleration
TI		initial value of time
ZI		initial value of z-coordinate pos. vector
ZVI		initial value of z-coordinate velocity vector
ALPHA		alpha in radians
SINA		sine of alpha
COSA		cosine of alpha
NGAMMA		number of points in gamma table
VOLTS(I)		voltage table
GRAMMA(I)		gamma energy table
NBETA		number of points in beta table
BNERGY(I)		beta energy table
SLAT		sine of launch latitude
CLAT		cosine of launch latitude
SLONG		sine of launch longitude
CLONG		cosine of launch longitude
IRUN		run number on binary I/p tape
ICOUNT		number of time points read in
OUT(I,J)		common input-output matrix
TL		launch time
YM		y-magnetometer reading
XM		x-magnetometer reading
CA(I)		coning axis vector
ZSUM		payload distance from center of earth

GLOSSARY OF TERMS (contd.)

Fortran Name	Formula Name	Description
XP		x-coordinate of payload in geo. coord. syst.
YP		y-coordinate of payload in geo. coord. syst.
ZP		z-coordinate of payload in geo. coord. syst.
ELAT		latitude of payload in geo. coord. syst.
ELONG		longitude of payload in geo. coord. syst.
CON1		longitude of payload minus longitude of launch
CON2		latitude of payload minus latitude of launch
CON3		sine of latitude of payload
CON4		cosine of latitude of payload
H		altitude of payload from earth surface
BM		field magnitude in (gauss)
BR		radial component of field (gauss)
BTHETA		northward component of field (gauss)
BPHI		eastward component of field (gauss)
FR(I)		theoretical field in J I coordinates
A(I,J)		direction cosines matrix
COSDX(I)		x-direction of detectors
COSDY(I)		y-direction of detectors
COSDZ(I)		z-direction of detectors

```
      SUBROUTINE ATUDE
C     CALCULATES DIRECTION COSINES OF X AND Y MAGNETOMETERS
      DIMENSION A(3,3),CA(3),CONST(7,7),F(7,7),FR(3),G(7,7)
      COMMON A,ALPHA,CA,CONST,COSA,F,FR,FREQ,G,GR,ISW1,ISW2,ISW3,PHASE,
     1RAD,RE,RHOI,RHOVI,RODDT,SINA,TI,TL,XM,YM,ZI,ZVI
      DIMENSION ATB(3),ATC(3),R(3),S(3),T(3)
      XMODF(I) = I-I/4*3
C     SWITCH TWO
      GO TO (200,100),ISW2
C     TURN SWITCH THREE ON
  100 ISW3 = 1
C     COMPUTE COMPONENTS OF E1BAR VECTOR
  200 DO 210 I=1,3
  210 R(I) = CA(I)
C     SWITCH THREE
      GO TO (500,900),ISW3
C     COMPUTE DOT PRODUCT OF MAGNETIC FIELD AND VELOCITY VECTORS
  500 DOTFV = 0.
      DO 510 I=1,3
  510 DOTFV = DOTFV + FR(I)*CA(I)
C     COMPUTE SINE OF ANGLE BETWEEN THESE VECTORS AND CHECK MAGNITUDE
      SIN2 = SQRTF(1.-DOTFV**2)
      IF(SIN2-1.E-5)600,600,700
C     ERROR
  600 PRINT 650,TL
  650 FORMAT(///10H WHEN TL =E14.7,34H, CONING AXIS COINCIDES WITH FIELD
     1//)
      GO TO 1700
  700 DO 710 I=1,3
  710 S(I) = (FR(I)-DOTFV*R(I))/SIN2
C     COMPUTE COMPONENTS OF E2BAR VECTOR
      DO 720 I=1,3
      J = XMODF(I+1)
      K = XMODF(I+2)
  720 T(I) = R(J)*S(K)-R(K)*S(J)
C     SWITCH TWO
      GO TO (800,900),ISW2
C     TURN SWITCH THREE OFF
  800 ISW3 = 2
  900 CALL CONF(TL,BCONE,GAMMA,ISW1)
C     TURN SWITCH ONE OFF
      ISW1 = 2
C     BEGIN ACTUAL COMPUTATIONS
      GAMMA = GAMMA/57.29578
      COSP = COSF(BCONE)
      SINP = SINF(BCONE)
      COSG = COSF(GAMMA)
      SING = SINF(GAMMA)
      SGCP = SING*COSP
      SGSP = SING*SINP
C     COMPUTE DIRECTION COSINES OF ROCKET AXIS VECTOR
      DO 910 I=1,3
  910 A(3,I) = SGCP*S(I)+SGSP*T(I)+COSG*R(I)
C     SWITCH TWO
      GO TO (1500,1000),ISW2
C     COMPUTE DOT PRODUCT OF ROCKET AXIS AND MAGNETIC FIELD VECTORS
 1000 IF(A(3,1)**2+A(3,2)**2+A(3,3)**2-.9)1025,1025,1050
C1025 ERROR
 1025 PRINT 1026,TL
```

```
 1026 FORMAT(9H WHEN TL=E14.7,34H, ROCKET AXIS IS NOT A UNIT VECTOR)
      GO TO 1700
 1050 AFDOT = 0.
      DO 1060 I=1,3
 1060 AFDOT = AFDOT+A(3,I)*FR(I)
      SIN1 = SQRTF(1.0-AFDOT*AFDOT)
      IF(SIN1-1.E-5)1100,1200,1200
C     ERROR
 1100 PRINT 1150,TL
 1150 FORMAT(///10H WHEN TL =E14.7,35H, PAYLOAD AXIS COINCIDES WITH FIEL
     1D//)
      GO TO 1700
C     COMPUTE COMPONENTS OF U2BAR VECTOR
 1200 DO 1210 I=1,3
 1210 ATB(I) = (FR(I)-AFDOT*A(3,I))/SIN1
C     COMPUTE COMPONENTS OF U3BAR VECTOR
      DO 1220 I=1,3
      J = XMODF(I+1)
      K = XMODF(I+2)
 1220 ATC(I) = A(3,J)*ATB(K)-A(3,K)*ATB(J)
C     COMPUTE MAGNETIC FIELD VECTOR IN X-Y PLANE
      SMTR = SQRTF(XM**2+YM**2)
      IF(SMTR-1.E-5)1300,1400,1400
C     ERROR
 1300 PRINT 1350,TL
 1350 FORMAT(9H WHEN TL=E14.7,23H, SMTR IS LESS THAN E-5)
      GO TO 1700
 1400 COSCHI = XM/SMTR
      SINCHI = -YM/SMTR
      GO TO 1600
 1500 CGCP = COSG*COSP
      CGSP = COSG*SINP
      DO 1510 I=1,3
      ATB(I) =-S(I)*SINP+T(I)*COSP
 1510 ATC(I) = SING*R(I)-(CGCP*S(I)+CGSP*T(I))
      ARG = FREQ*TL-PHASE
      COSCHI = COSF(ARG)
      SINCHI = SINF(ARG)
C     COMPUTE DIRECTION COSINES OF X,Y MAGNETOMETERS
 1600 DO 1610 I=1,3
      A(1,I) = COSCHI*ATB(I)+SINCHI*ATC(I)
 1610 A(2,I) = COSCHI*ATC(I)-SINCHI*ATB(I)
      GO TO 1800
C     SET DIRECTION COSINES TO ZERO
 1700 DO 1710 I=1,3
      DO 1710 J=1,3
 1710 A(I,J) = 0.
 1800 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TRAJ(T,X,Y,Z,DCVX,DCVY,DCVZ,ER,H)
      DIMENSION A(3,3),CA(3),CONST(7,7),F(7,7),FR(3),G(7,7)
      COMMON A,ALPHA,CA,CONST,COSA,F,FR,FREQ,G,GR,ISW1,ISW2,ISW3,PHASE,
     1RAD,RE,RHOI,RHOVI,RODDT,SINA,TI,TL,XM,YM,ZI,ZVI
      TMTI = T-TI
C     DETERMINE MAGNITUDE OF HORIZONTAL POSITION VECTOR
      RHO = RHOI+TMTI*(RHOVI+.5*RODDT*TMTI)
C     DETERMINE X,Y, AND Z COORDINATES OF POSITION VECTOR
      X = RHO*SINA
      Y = RHO*COSA
      Z = ZI+TMTI*(ZVI-.5*GR*TMTI)
C     DETERMINE XV,YV, AND ZV COORDINATES OF VELOCITY VECTOR
      XV = (RODDT*TMTI + RHOVI)*SINA
      YV = COSA*(RODDT*TMTI + RHOVI)
      ZV = ZVI-GR*TMTI
C     DETERMINE MAGNITUDE OF VELOCITY VECTOR
      V = SQRTF(XV**2+YV**2+ZV**2)
C     DETERMINE DIRECTION COSINES OF VELOCITY VECTOR
      DCVX = XV/V
      DCVY = YV/V
      DCVZ = ZV/V
C     DETERMINE ALTITUDE
      H = (RHO**2+Z**2+2.*Z*RE)/(SQRTF(RHO**2+(Z+RE)**2)+RE)
C     DETERMINE EARTH RANGE
      ER = RE*ATANF(RHO/(Z + RE))
      RETURN
      END
```

```
      SUBROUTINE MAGNET(H,ELAT,ELONG,B,BR,BTHETA,BPHI)
      DIMENSION A(3,3),CA(3),CONST(7,7),F(7,7),FR(3),G(7,7)
      COMMON A,ALPHA,CA,CONST,COSA,F,FR,FREQ,G,GR,ISW1,ISW2,ISW3,PHASE,
     1RAD,RE,RHOI,PHOVI,RODDT,SINA,TI,TL,XM,YM,ZI,ZVI
      DIMENSION AOR(8),CP(7),DP(7,7),P(7,7),SP(7)
C     H = ALTITUDE IN KILOMETERS
C     ELAT = EARTH LATITUDE IN RADIANS
C     ELONG = EARTH LONGITUDE IN RADIANS
C     B = MAGNETIC FIELD MAGNITUDE IN GAUSS
C     BR = RADIAL COMPONENT IN GAUSS
C     BTHETA = NORTHWARD COMPONENT IN GAUSS
C     BPHI = EASTWARD COMPONENT IN GAUSS
      THETA = 1.57079634-ELAT
      PHI = ELONG
      R = H+6371.2
      C = COSF(THETA)
      S= SINF(THETA)
C     MULTIPLE ANGLE FORMULAE
      SP(1)=0.0
      CP(1)=1.0
      SP(2)=SINF(PHI)
      CP(2)= COSF(PHI)
      DO 50 M=3,7
      SP(M) = SP(2)*CP(M-1)+CP(2)*SP(M-1)
   50 CP(M) = CP(2)*CP(M-1)-SP(2)*SP(M-1)
C     POWERS OF A/R
      AOR(1) = 6371.2/R
      DO 60 I = 2,8
   60 AOR(I) = AOR(1)*AOR(I-1)
      BR = 0.
      BTHETA = 0.
      BPHI = 0.
      DO 70 L1=1,7
      DO 70 L2=1,7
      P(L1,L2) = 0.
   70 DP(L1,L2) = 0.
      P(1,1) = 1.0
      P(2,1) = C
      P(2,2) = S
      DP(2,1)=-S
      DP(2,2)=C
      TS1= F(2,1)*CP(1)+ G(2,1)*SP(1)
      TS2= F(2,2)*CP(2)+ G(2,2)*SP(2)
      BR= AOR(2)*F(1,1)+2.0*AOR(3)*(P(2,1)*TS1+P(2,2)*TS2)
      BTHETA=-AOR(3)*(DP(2,1)*TS1+ DP(2,2)*TS2)
      BPHI=-AOR(3)*P(2,2)*(-F(2,2)*SP(2)+G(2,2)*CP(2))
      DO 120 N = 3,7
      FN = N
      SUMR = 0.
      SUMT = 0.
      SUMP = 0.
      DO 110 M = 1,N
C     GENERATION OF ASSOCIATED LEGENDRE POLYNOMIALS
      IF (N-M) 90,80,90
   80 K = M-1
      P(N,M) = S*P(N-1,K)
      DP(N,M) = S*DP(N-1,K)+C*P(N-1,K)
      GO TO 100
   90 P(N,M) = C*P(N-1,M)-CONST(N,M)*P(N-2,M)
```

```
      DP(N,M) = C*DP(N-1,M)-S*P(N-1,M)-CONST(N,M)*DP(N-2,M)
  100 CONTINUE
      FM = M-1
C     COMPUTE SUMMATIONS
      TS = F(N,M)*CP(M)+G(N,M)*SP(M)
      SUMR = SUMR+P(N,M)*TS
      SUMT = SUMT+DP(N,M)*TS
  110 SUMP = SUMP+FM*P(N,M)*(-F(N,M)*SP(M)+G(N,M)*CP(M))
      BR = BR+AOR(N+1)*FN*SUMR
      BTHETA = BTHETA-AOR(N+1)*SUMT
      BPHI = BPHI-AOR(N+1)*SUMP
  120 CONTINUE
      BPHI = BPHI/S
      B = SQRTF(BR*BR+BTHETA*BTHETA+BPHI*BPHI)
C     SWITCH FROM JENSEN-CAIN SYSTEM TO EOS SYSTEM
      BR = -BR
      BPHI = -BPHI
      RETURN
      END
```

```
CCONE     SUBROUTINE CONE FOR ROCKET NO. 19
      SUBROUTINE CONE (TL,BCONE,GAMMA,ISW1)
      DIMENSION X1(7),X2(7),Y1(7),Y2(7)
      N=7
      T = TL+7686.4
      GO TO (10,30),ISW1
   10 X1(1)=7735.
      X1(2)=7739.72
      X1(3)=7745.57
      X1(4)=7752.17
      X1(5)=7761.91
      X1(6)=7774.59
      X1(7)=7787.29
      X2(1)=7737.44
      X2(2)=7742.
      X2(3)=7749.14
      X2(4)=7755.21
      X2(5)=7768.61
      X2(6)=7780.56
      X2(7)=7794.01
      Y1(1)=0.
      Y1(2)=3.4
      Y1(3)=4.916
      Y1(4)=2.90
      Y1(5)=8.117
      Y1(6)=7.634
      Y1(7)=7.935
      PI=3.14159268
      DT = 2.*PI/.2439
      TU = X2(N)
      DO 20 I=1,N
      XI=I-1
   20 Y2(I)=XI*PI
   30 IF(T-X1(1))40,40,50
   40 GAMMA=0.
      GO TO 65
   50 IF(T-X2(1))60,60,70
   60 GAMMA=FCN (T,X1,Y1,1)
   65 BCONE=0.
      GO TO 310
   70 IF(T-X1(2))80,90,100
   80 GAMMA=FCN (T,X1,Y1,1)
      GO TO 95
   90 GAMMA=Y1(2)
   95 BCONE=FCN (T,X2,Y2,1)
      GO TO 310
  100 IF(T-X2(2))110,120,130
  110 BCONE=FCN (T,X2,Y2,1)
      GO TO 125
  120 BCONE=Y2(2)
  125 GAMMA=((X1(3)-T)*FCN (T,X1,Y1,1)+(T-X1(2))*FCN (T,X1,Y1,2))/(X1(3)
     1-X1(2))
      GO TO 310
  130 M=N-2
      DO 140 I=3,M
      IF(T-X1(I))260,270,135
  135 IF(T-X2(I))280,290,140
  140 CONTINUE
      I=N-1
```

```
      IF(T-X1(I))260,160,170
  160 GAMMA=Y1(I)
      GO TO 285
  170 IF(T-X2(I))180,190,200
  180 GAMMA=FCN (T,X1,Y1,M)
      GO TO 285
  190 BCONE=Y2(I)
      GO TO 215
  200 IF(T-X1(N))210,220,230
  210 BCONE=FCN (T,X2,Y2,M)
  215 GAMMA=FCN (T,X1,Y1,M)
      GO TO 310
  220 GAMMA=Y1(N)
      GO TO 245
  230 IF(T-X2(N))240,250,300
  240 GAMMA=Y1(N)
  245 BCONE=FCN (T,X2,Y2,M)
      GO TO 310
  250 BCONE=Y2(N)
      GAMMA = Y1(N)
      GO TO 310
  260 GAMMA=((X1(I)-T)*FCN (T,X1,Y1,I-2)+(T-X1(I-1))*FCN (T,X1,Y1,I-1))/
     1(X1(I)-X1(I-1))
      GO TO 285
  270 GAMMA=Y1(I)
      GO TO 285
  280 GAMMA=((X1(I+1)-T)*FCN (T,X1,Y1,I-1)+(T-X1(I))*FCN (T,X1,Y1,I))/(X
     11(I+1)-X1(I))
  285 BCONE=((X2(I)-T)*FCN (T,X2,Y2,I-2)+(T-X2(I-1))*FCN (T,X2,Y2,I-1))/
     1(X2(I)-X2(I-1))
      GO TO 310
  290 BCONE=Y2(I)
      GAMMA=((X1(I+1)-T)*FCN (T,X1,Y1,I-1)+(T-X1(I))*FCN (T,X1,Y1,I))/(X
     11(I+1)-X1(I))
      GO TO 310
  300 GAMMA=Y1(N)
  302 IF(T-(TU+DT))306,306,304
  304 TU = TU + DT
  306 BCONE = .2439*(T-TU)
  310 RETURN
      END
```

```
      FUNCTION ATAN1(Y,X)
C     THIS SUBROUTINE CALCULATES THE ARCTANGENT OF (Y/X) IN THE INTERVAL
C     -PI TO +PI.  IF Y AND X ARE ZERO, THEN ATAN1F(Y,X) IS SET TO ZERO.
      IF(Y)10,70,10
   10 IF(X)20,30,40
   20 ATAN1=3.14159268-ATANF(ABSF(Y/X))
      GO TO 50
   30 ATAN1=1.57079634
      GO TO 50
   40 ATAN1=ATANF(ABSF(Y/X))
   50 IF(Y)60,100,100
   60 ATAN1=-ATAN1
      GO TO 100
   70 IF(X)80,90,90
   80 ATAN1=3.14159268
      GO TO 100
   90 ATAN1=0.
  100 RETURN
      END
```

```
      FUNCTION FCN(XP,XOYT+)
      DIMENSION X(1),Y(1)
      XMODF(I) = I-I/4*3
      FCN =0.
      DO 20 J=1,3
      M=I+J-1
      YP=Y(M)
      DO 10 L=1,2
      N = I+XMODF(J+L)-1
   10 YP=YP*(XP-X(N))/(X(M)-X(N))
   20 FCN=FCN+YP
      RETURN
      END
```

```
CMAIN
C     ATTITUDE DETERMINATION PROGRAM
      DIMENSION A(3,3),CA(3),CONST(7,7),F(7,7),FR(3),G(7,7),OUT(46,200)
      COMMON A,ALPHA,CA,CONST,COSA,F,FR,FREQ,G,GR,ISW1,ISW2,ISW3,PHASE,
     1RAD,RE,RHOI,RHOVI,RODOT,SINA,TI,TL,XM,YM,ZI,ZVI
      DIMENSION BNERGY(68),COSDX(3),COSDY(3),COSDZ(3),CPHI(3),CTHETA(3),
     1DPHI(3),DTHETA(3),GRAMMA(68),PHI(3),SCOSQ(3),SPHI(3),STHETA(3),
     2THETA(3),TRIG1(3),TRIG2(3),VOLTS(68)
C     TSTART = TIME TO START PROCESSING IN SECONDS FROM LAUNCH
C     TSTOP = TIME TO STOP PROCESSING IN SECONDS FROM LAUNCH
C     BIAS = BURST TIME IN SYSTEM TIME
C     GBIAS = LAUNCH TIME IN SYSTEM TIME
C     FLAT = LAUNCH LATITUDE IN DEGREES
C     FLONG = LAUNCH LONGITUDE IN DEGREES(EAST OF GREENWICH)
C     BAAL = BURST ALTITUDE IN KILOMETERS
C     NGAMMA = LENGTH OF GAMMA/VOLTS TABLE
C     NBETA = LENGTH OF BETA ENERGY CONVERSION TABLE
C     POTMET = PHOTOMETER MULTIPLYING FACTOR
C     BCONE = TOTAL CONING ANGLE RADIANS
C     FREQ = SPIN FREQUENCY IN RADIANS PER SECOND
C     GAMMA = HALF CONE ANGLE IN DEGREES
C     PHASE = DELTA(PHASE ANGLE)IN RADIANS
C     THETA(1) = ELEVATION ANGLE OF VGS20 IN DEGREES
C     THETA(2) = ELEVATION ANGLE OF HGS20 IN DEGREES
C     THETA(3) = ELEVATION ANGLE OF BETA DETECTOR/PHOTOMETER IN DEGREES
C     PHI(1) = AZIMUTH ANGLE(FROM Y) OF VGS20 IN DEGREES
C     PHI(2) = AZIMUTH ANGLE OF HGS20 IN DEGREES
C     PHI(3) = AZIMUTH ANGLE OF BETA DETECTOR/PHOTOMETER IN DEGREES
C     SWITCH DISCRIPTION
C     SWITCH ONE
C         ON IF SUBROUTINE CONE HAS NOT BEEN CALLED
C         OFF IF SUBROUTINE CONE HAS BEEN CALLED
C     SWITCH TWO
C           ON IF TL IS IN (TLA,TLB)
C           OFF IF IL IS NOT IN (TLA,TLB)
C     SWITCH THREE
C           ON IF RI AND FRI VECTORS HAVE CHANGED
C           OFF IF RI AND FRI VECTORS ARE CONSTANT
    9 FORMAT(8E9.2)
   10 FORMAT (6E12.8)
   11 FORMAT(I2/(8E9.2))
   12 FORMAT(I2/(18F4.2))
   13 FORMAT (I2/(6E12.8))
C     SET UP CONSTANTS
      RAD = 57.2957800
      TPI = 6.28318536
      FLAT = 16.734250
      FLONG = 169.528189
      NPAGE = 0
C     RE = EARTH RADIUS IN KILOMETERS
      RE = 6371.2
      F(1,1) = 0.
      F(2,1) = 30411.2
      F(3,1) = 2403.5
      F(4,1) = -3151.8
      F(5,1) = -4179.4
      F(6,1) = 1625.6
      F(7,1) = -1952.3
      F(2,2) = 2147.4
```

```
      F(3,2) = -5125.3
      F(4,2) = 6213.0
      F(5,2) = -4529.8
      F(6,2) = -3440.7
      F(7,2) = -485.3
      F(3,3) = -1338.1
      F(4,3) = -2489.8
      F(5,3) = -2179.5
      F(6,3) = -1944.7
      F(7,3) = 321.2
      F(4,4) = -649.6
      F(5,4) = 700.8
      F(6,4) = -60.8
      F(7,4) = 2141.3
      F(5,5) = -204.4
      F(6,5) = 277.5
      F(7,5) = 105.1
      F(6,6) = 69.7
      F(7,6) = 22.7
      F(7,7) = 111.5
      G(1,1) = 0.
      G(2,1) = 0.
      G(3,1) = 0.
      G(4,1) = 0.
      G(5,1) = 0.
      G(6,1) = 0.
      G(7,1) = 0.
      G(2,2) = -5798.9
      G(3,2) = 3312.4
      G(4,2) = 1487.0
      G(5,2) = -1182.5
      G(6,2) = -79.6
      G(7,2) = -575.8
      G(3,3) = -157.9
      G(4,3) = -407.5
      G(5,3) = 1000.6
      G(6,3) = -200.0
      G(7,3) = -873.5
      G(4,4) = 21.0
      G(5,4) = 43.0
      G(6,4) = 459.7
      G(7,4) = -340.6
      G(5,5) = 138.5
      G(6,5) = 242.1
      G(7,5) = -11.8
      G(6,6) = -121.8
      G(7,6) = -111.6
      G(7,7) = -32.5
      DO 20 I=1,7
      DO 20 J=1,I
      F(I,J) = F(I,J)*1.0E-5
   20 G(I,J) = G(I,J)*1.0E-5
C     COMPUTE CONST
      DO 30 N = 1,7
      FN = N
      DO 30 M = 1,N
      FM = M
   30 CONST(N,M) = ((FN-2.0)**2-(FM-1.0)**2)/((FN+FN-3.0)*(FN+FN-5.0))
C     INITIALIZE DETECTOR ANGLES
```

```
      THETA(1) = 0.0
      THETA(2) = -15.0
      THETA(3) = 0.0
      PHI(1) = 0.0
      PHI(2) = 45.0
      PHI(3) = 90.0
      DO 15 I = 1,3
      STHETA(I) = SINF(THETA(I)/RAD)
      CTHETA(I) = COSF(THETA(I)/RAD)
      SPHI(I) = SINF(PHI(I)/RAD)
      CPHI(I) = COSF(PHI(I)/RAD)
      TRIG1(I) = CTHETA(I)*SPHI(I)
   15 TRIG2(I) = CTHETA(I)*CPHI(I)
      DO 17 I=41,68
      BNERGY(I)=0.
      VOLTS(I)=0.
   17 GRAMMA(I)=0.
C     TURN SWITCHES ONE AND THREE ON
      ISW1 = 1
      ISW3 = 1
C     READ CONTROL CARD
      READ INPUT TAPE 5,10,BIAS,XB,YB,ZB
C     INPUT ROCKET NUMBER AND ASSOCIATED CONSTANTS
      READ INPUT TAPE 5,13,NROCKT,TSTART,TSTOP,GBIAS,POTMET,TLA,TLB,FREQ
     1,PHASE,TA
C     INPUT CONDITIONS FOR ROCKET TRAJECTORY
      READ INPUT TAPE 5,10,ALPHR,GR,RHOI,RHOVI,RODDT,TI,ZI,ZVI
C     CONVERT ALPHA TO RADIANS AND COMPUTE SINA AND COSA
      ALPHA = ALPHR/RAD
      SINA = SINF(ALPHA)
      COSA = COSF(ALPHA)
C     READ IN TOTAL GAMMA DETECTOR ENERGY CONVERSION TABLE
      READ INPUT TAPE 5,12,NGAMMA,(VOLTS(I),I=1,NGAMMA)
      READ INPUT TAPE 5,9,(GRAMMA(I),I=1,NGAMMA)
C     READ IN BETA CONVERSION TABLE
      READ INPUT TAPE 5,11,NBETA,(BNERGY(I),I=1,NBETA)
C     OUTPUT INPUT LIST
      WRITE OUTPUT TAPE 6,35,NROCKT,TSTART,TLA,POTMET,TSTOP,TLB,FREQ,GBI
     1AS,TA,PHASE
   35 FORMAT(1H144X28HINPUT DATA FOR ROCKET NUMBERI3//1H08X18HCONTROL PA
     1REMETERS/1H013X8HTSTART =F5.1,4H SEC13X5HTLA =1PE8.1,4H SEC13X8HPO
     2TMET =E9.2,26H WATT/CM**2/STERADIAN/VOLT/1H013X7HTSTOP =0PF6.1,4H
     3SEC13X5HTLB =1PE8.1,4H SEC13X6HFREQ =E14.8,8H RAD/SEC/1H013X7HGBIA
     4S =E11.4,4H SEC8X4HTA =0PF10.4,4H SEC12X7HPHASE =1PE14.8,4H RAD//)
      WRITE OUTPUT TAPE 6,36,ALPHR,TI,RHOI,RODDT,FLAT,RE,RHOVI,GR,FLONG,
     1ZI,ZVI
   36 FORMAT(1H08X32HCONDITIONS FOR ROCKET TRAJECTORY/1H013X7HALPHA =F10
     1.5,4H DEG10X4HTI =F6.1,4H SEC11X7HRHOI  =F7.3,3H KM14X7HRODDT =1PE
     211.4/1H013X7HFLAT  =0PF10.5,4H DEG10X4HRE =F7.1,3H KM11X7HRHOVI =
     3F7.4,7H KM/SEC10X7HG     =1PE11.4/1H013X7HFLONG =0PF10.5,4H DEG10X
     44HZI =F8.3,3H KM10X7HZVI   =F7.4,7H KM/SEC///)
      WRITE OUTPUT TAPE 6,37
   37 FORMAT(49X21HBETA CONVERSION TABLE/48X23H(FLUX IN MEV/CM**2/SEC)//
     14X6(5HVOLTS4X4HFLUX6X)//)
      DIMENSION P(6)
      DO 38 I=1,6
   38 P(I)=0.
      DO 40 I=1,NBETA,6
      P(1)=P(6)+.1
```

```
      DO 39 J=2,6
   39 P(J)=P(J-1)+.1
   40 WRITE OUTPUT TAPE 6,41,P(1),BNERGY(I),P(2),BNERGY(I+1),P(3),BNERGY
     1(I+2),P(4),BNERGY(I+3),P(5),BNERGY(I+4),P(6),BNERGY(I+5)
   41 FORMAT(6(0PF9.2,1X1PE9.2))
      WRITE OUTPUT TAPE 6,42
   42 FORMAT(///48X22HGAMMA CONVERSION TABLE/48X23H(FLUX IN MEV/CM**2/SE
     1C)//4X6(5HVOLTS4X4HFLUX6X)//)
      WRITE OUTPUT TAPE 6,41,(VOLTS(I),GRAMMA(I),VOLTS(I+1),GRAMMA(I+1),
     1VOLTS(I+2),GRAMMA(I+2),VOLTS(I+3),GRAMMA(I+3),VOLTS(I+4),GRAMMA(I+
     24),VOLTS(I+5),GRAMMA(I+5),I=1,NGAMMA,6)
C     CALCULATE ELEMENTS OF ROTATION OPERATOR
      SLAT = SINF(FLAT/RAD)
      CLAT = COSF(FLAT/RAD)
      SLONG = SINF(FLONG/RAD)
      CLONG = COSF(FLONG/RAD)
      TSTART = TSTART+GBIAS
      TSTOP = TSTOP+GBIAS
C     READ BINARY INPUT RECORDS
C        READ RUN NUMBER
      READ TAPE 10, IRUN
      IF(NROCKT-IRUN)45,53,45
   45 PRINT 50
   50 FORMAT(///52H WRONG INPUT TAPE WAS MOUNTED ON B-5. RUN CANCELLED.)
      CALL EXIT
C     WRITE RUN NUMBER
   53 WRITE TAPE 9,IRUN
C        READ INPUT DATA
   55 READ TAPE 10,ICOUNT,((OUT(I,J),I=1,15),J=1,ICOUNT)
C     CHECK STARTING AND STOPPING TIMES
      IF(OUT(1,1)-TSTART)62,65,60
   60 IF(OUT(1,1)-TSTOP)65,65,5000
   62 IF(OUT(1,ICOUNT)-TSTART)55,65,65
   65 CONTINUE
      DO 200 K=1,ICOUNT
      TL = OUT(1,K) - GBIAS
      YM = OUT(7,K)
      XM = OUT(8,K)
      OUT(1,K) = OUT(1,K)-BIAS
C     CHECK IF TL IS IN (TLA,TLB)
      IF(TL-TLA)72,71,70
   70 IF(TL-TLB)71,71,72
C     TURN SWITCH 2 ON
   71 ISW2 = 1
      T2 = TL
      GO TO 73
C     TURN SWITCH 2 OFF
   72 ISW2 = 2
      T2 = TL
C     CHECK IF PAYLOAD ABOVE LIMIT OF ATMOSPHERE
   73 IF(TL-TA)74,77,77
C     SWITCH TWO
   74 GO TO (75,76),ISW2
   75 T1 = TLA
      GO TO 80
   76 T1 = TL
      GO TO 80
   77 T1 = TA
C     COMPUTE CA VECTOR
```

```
C     DETERMINE COORDINATES OF CONING AXIS VECTOR
   80 CALL TRAJ(T1,XA,YA,ZA,XADOT,YADOT,ZADOT,ERA,HA)
      CA(1) = XADOT
      CA(2) = YADOT
      CA(3) = ZADOT
C     COMPUTE VEHICLE POSITION AND VELOCITY AT GAMMA SCANNER TIME T
      CALL TRAJ(T2,X,Y,Z,XDOT,YDOT,ZDOT,ER,H)
C     ROTATE FROM J.I. TO GEOCENTRIC COORDINATES
      ZSUM = Z+RE
      ZP = ZSUM*CLAT-Y*SLAT
      XP = ZP*CLONG-X*SLONG
      YP = ZP*SLONG+X*CLONG
      ZP = Y*CLAT+ZSUM*SLAT
C     COMPUTE LATITUDE AND LONGITUDE OF PAYLOAD AT TIME,T
      ELAT = ATANF(ZP/SQRTF(XP*XP+YP*YP))
      ELONG = ATAN1 (YP,XP)
C     CALCULATE ELEMENTS OF ROTATION OPERATOR
      CON1 = ELONG-FLONG/RAD
      CON2 = ELAT-FLAT/RAD
      CON3 = SINF(ELAT)
      CON4 = COSF(ELAT)
C     DETERMINE EAST,NORTH AND VERTICAL MAGNETIC FIELD COMPONENTS
      CALL MAGNET(H,ELAT,ELONG,BM,BR,BTHETA,BPHI)
C     COMPUTE FR VECTOR
C     ROTATE INTO J.I. COORDINATES FROM GEOCENTRIC COORDINATE SYSTEM AND
C     THEN CALCULATE THE DIRECTION COSINES OF THE MAGNETIC FIELD VECTOR
      FR(1) = (BPHI+CON1*(CON4*BR-CON3*BTHETA))/BM
      FR(2) = (CON1*SLAT*BPHI+BTHETA+CON2*BR)/BM
      FR(3) = (-CON1*CLAT*BPHI-CON2*BTHETA+BR)/BM
      CALL ATUDE
C     DETERMINE DIRECTION COSINES OF DETECTORS IN PAYLOAD WITH
C     RESPECT TO EAST-NORTH-VERTICAL SYSTEM
      DO 85 I = 1,3
      COSDX(I) = A(1,1)*TRIG1(I)+A(2,1)*TRIG2(I)+A(3,1)*STHETA(I)
      COSDY(I) = A(1,2)*TRIG1(I)+A(2,2)*TRIG2(I)+A(3,2)*STHETA(I)
      COSDZ(I) = A(1,3)*TRIG1(I)+A(2,3)*TRIG2(I)+A(3,3)*STHETA(I)
C     COMPUTE DETECTOR ATTITUDES
      DPHI(I) = ATAN1 (COSDX(I),COSDY(I))
   85 DTHETA(I) = ATANF(COSDZ(I)/SQRTF(1.-COSDZ(I)**2))
C     OUTPUT ROUTINE
C     GENERATE THE 46-ITEM OUTPUT RECORDS
C     VERTICAL GAMMA SCANNER(20 AND 90 DEGS) IN COUNTS/10 MSECS.
C     HORIZONTAL GAMMA SCANNER(20 AND 90 DEGS)IN COUNTS/10 MSECS
      DO 1086 I=2,5
 1086 OUT(I,K) = OUT(I,K)*1.E-2
C     POSITION OF PAYLOAD IN KILOMETERS
      OUT(16,K) = X
      OUT(17,K) = Y
      OUT(18,K) = Z
C     ALTITUDE OF VEHICLE IN KILOMETERS
      OUT(19,K) = H
C     THEORETICAL FIELD COMPONENTS IN J.I. COORDINATES
      OUT(20,K) = FR(1)*BM
      OUT(21,K) = FR(2)*BM
      OUT(22,K) = FR(3)*BM
C     DIRECTION COSINES OF X,Y,Z MAGNETOMETERS
      L = 22
      DO 86 I=1,3
      DO 86 J=1,3
```

```
      L = L+1
   86 OUT(L,K) = A(I,J)
C     AZIMUTH AND ELEVATION
C          VERTICAL GAMMA SCANNER (20DEG) IN DEGS., OUT(32,K),OUT(35,K)
C          HORIZONTAL GAMMA SCANNER (20DFG) IN DEGS., OUT(33,K),OUT(36,K)
C          BETA DETECTOR/PHOTOMETER IN DEGS., OUT(34,K),OUT(37,K)
      DO 87 I=1,3
      L = L+1
      OUT(L,K) = DPHI(I)*RAD
   87 OUT(L+3,K) = DTHETA(I)*RAD
C     RANGE (BURST TO PAYLOAD) IN METERS
      OUT(38,K) = SQRTF((X-XB)**2+(Y-YB)**2+(Z-ZB)**2)
C     AZIMUTH AND ELEVATION OF PAYLOAD-BURST POSITION VECTOR IN DEGREES
      OUT(39,K) = RAD*ATAN1 (X-XB,Y-YB)
C     OUT(40,K) = RAD*ARSIN((Z-ZB)/OUT(38,K))
      XX = Z-ZB
      OUT(40,K) = RAD*ATANF(XX/SQRTF(OUT(38,K)**2-XX**2))
C     AZIMUTH AND ELEVATION OF ROCKET AXIS IN DEGREES
      OUT(41,K) = RAD*ATAN1(A(3,1),A(3,2))
C     OUT(42,K) = RAD*ARSIN(A(3,3))
      OUT(42,K) = RAD*ATANF(A(3,3)/SQRTF(1.-A(3,3)**2))
C     PHOTOMETER FUNCTIONAL VALUE IN WATTS/(CMS**2)/STERADIANS
      OUT(43,K) = OUT(12,K)*POTMET
C     BETA DETECTOR FUNCTIONAL VALUE IN MEV/CM**2/SEC
      I = 1
      NBVLTS = 10.*OUT(10,K)
      IF(NBVLTS)94,94,90
   90 IF(NBVLTS-NBETA)96,92,92
   92 I = NBETA
   94 OUT(44,K) = BNERGY(I)
      GO TO 100
   96 BVOLTS = NBVLTS
      OUT(44,K) = BNERGY(NBVLTS)+(BNERGY(NBVLTS+1)-BNERGY(NBVLTS))*
     1(10.*OUT(10,K)-BVOLTS)
C     TOTAL GAMMA DETECTOR FUNCTIONAL VALUE IN MEV/((CM**2)*SEC))
  100 I = 1
      IF(OUT(11,K)-VOLTS(1))130,130,110
  110 DO 120 I=2,NGAMMA
      IF(OUT(11,K)-VOLTS(I))140,130,120
  120 CONTINUE
      I = NGAMMA
  130 OUT(45,K) = VOLTS(I)
      GO TO 200
  140 OUT(45,K) = GRAMMA(I-1)+(OUT(11,K)-VOLTS(I-1))/(VOLTS(I)-VOLTS(I
     1-1))*(GRAMMA(I)-GRAMMA(I-1))
C     ANGLE BETWEEN BETA DETECTOR AND MEASURED FIELD
C     OUT(46,K) = RAD*ARCOSF(XM/(XM**2+YM**2+ZM**2))
  200 OUT(46,K) = RAD*ATAN1 (SQRTF((XM**2+YM**2+ZM**2)**2-XM**2),XM)
C     END OF MAIN LOOP
C     WRITE BINARY OUTPUT TAPE
      WRITE TAPE 9,ICOUNT,((OUT(I,J),I=1,46),J=1,ICOUNT)
      KKK = (ICOUNT-ICOUNT/50*50+49)/50+ICOUNT/50
      DO 240 K=1,KKK
      N = 50*K
      M=N-49
      NPAGE = NPAGE + 1
      I = NPAGE
      WRITE OUTPUT TAPE12,210,NROCKT,I,(OUT(1,J),OUT(16,J),OUT(17,J),OUT
     1(18,J),OUT(19,J),OUT(10,J),OUT(11,J),OUT(12,J),OUT(8,J),OUT(7,J),O
```

```
     2UT(9,J),OUT(6,J),OUT(14,J),OUT(13,J),OUT(15,J),J=M,N)
 210 FORMAT(1H18X6HBOOK 122X53HOUTPUT FROM ATTITUDE DETERMINATION PROGR
     1AM FOR ROCKETI3,18X4HPAGEI5///25X19HPAYLOAD POSITION IN16X16HDETEC
     2TOR OUTPUTS5X12HMAGNETOMETER26X1HC/11X6HH-TIME9X16HJ.I. COORDINATE
     3S 7X8HALTITUDE3X17HBETA TOTAL PHOTO-6X8HREADINGS8X3HAGC4X14HDIFF
     4GAIN    0/25X1HX8X1HY8X1HZ9X1HH11X11HGAMMA METER4X2HXM4X2HYM4X2HZM
     518X8HRATIO   D/119X1HE/12X5H(SEC)7X4H(KM)5X4H(KM)5X4H(KM)oX4H(KM) 8
     6X7H(VOLTS)12X7H(GAUSS)8X4H(MV)   //(F19.4,1X3F9.3,F10.3,1X3F6.2,1X3
     7F6.3,F8.1,2E7.3,2XA1))
      WRITE OUTPUT TAPE 6,220,NROCKT,I,(OUT(1,J),OUT(38,J),OUT(39,J),OUT
     1(40,J),OUT(41,J),OUT(42,J),OUT(34,J),OUT(37,J),OUT(46,J),OUT(32,J)
     2,OUT(35,J),OUT(33,J),OUT(36,J),J=M,N)
 220 FORMAT(1H18X6HBOOK 222X53HOUTPUT FROM ATTITUDE DETERMINATION PROGR
     1AM FOR ROCKETI3,18X4HPAGEI5///25X16X                   7X11HROCKET AX
     2IS4X25HBETA DETECTOR ORIENTATION7X21H20 DEG. GAMMA SCANNER/11X6HH-
     3TIME8X2X1HA6X1HB6X1HC6X    11HORIENTATION5X5HAZIM.2X5HELEV.3X8HANGL
     4E TO13X11HORIENTATION/24X13X                    2X5X     4X5HAZIM.
     5       2X5HELEV.17X11HEARTH FIELD7X8HVERTICAL4X10HHORIZONTAL/93X5HA
     6ZIM.2X5HELEV.2X5HAZIM.2X5HELEV./12X5H(SEC)8X19X
     7   4X5H(DEG)2X5H(DEG)4X5H(DEG)2X5H(DEG)4X5H(DEG)8X5H(DEG)3(2X5H(DEG
     8)))//(F19.4,F11.2,2F7.1,2X2F7.1,2X2F7.1,F9.1,6X4F7.1))
      WRITE OUTPUT TAPE13,230,NROCKT,I,(OUT(1,J),OUT(3,J),OUT(5,J),OUT(2
     1,J),OUT(4,J),OUT(44,J),OUT(45,J),OUT(43,J),OUT(20,J),OUT(21,J),OUT
     2(22,J),J=M,N)
 230 FORMAT(1H18X6HBOOK 322X53HOUTPUT FROM ATTITUDE DETERMINATION PROGR
     1AM FOR ROCKETI3,18X4HPAGEI5///24X21HGAMMA SCANNER OUTPUTS11X26HDET
     2ECTOR FUNCTIONAL VALUES8X28HTHEORETICAL FIELD COMPONENTS/11X6HH-TI
     3ME6X9H90 DEGREE5X9H20 DEGREE7X4HBETA5X5HTOTAL28X19HIN J.I. COORDIN
     4ATES/22X5HHORIZ3X4HVERT2X5HHORIZ3X4HVERT14X5HGAMMA6X
     510HPHOTOMETER8X5HFR(1)6X5HFR(2)6X5HFR(3)//12X5H(SEC)10X16H(COUNTS/
     610 MSEC)9X15H(MEV/CM**2/SEC)12X17H(WATT/CM**2/STER)3(4X7H(GAUSS))//
     7(F19.4,1X4F7.2,1X1P2E10.2,4XE9.2,5X0P3F11.8))
 240 CONTINUE
C     READ IN NEXT DATA RECORD
      GO TO 55
C     WRITE END-OF-FILE ON OUTPUT TAPE
5000  END FILE 9
      END FILE 12
      END FILE 13
      CALL REWULD (9)
      CALL REWULD (10)
      CALL REWULD (12)
      CALL REWULD (13)
      CALL EXIT
      END
```

TABLE 3.1 INPUTS FOR TRAJ SUBROUTINE

Rocket	α	t_o (sec) from launch	z_o (km)	$\dot{z}_o$ (km/sec)	ρ_o (km)	$\dot{\rho}_o$ (km/sec)	$\ddot{\rho}_o$ (km/sec^2)
8	$26^\circ 12'$	110	137.740	2.7770	58.310	1.6350	5.46×10^{-4}
9	$23^\circ 30'$	110	140.620	2.9370	40.710	1.1686	4.78×10^{-4}
15	21°	40	30.520	1.4190	9.030	0.4964	0
19	135°	30	29.830	1.5790	5.730	0.2937	0
26	$113^\circ 30'$	35	29.834	1.5790	5.729	0.2937	0

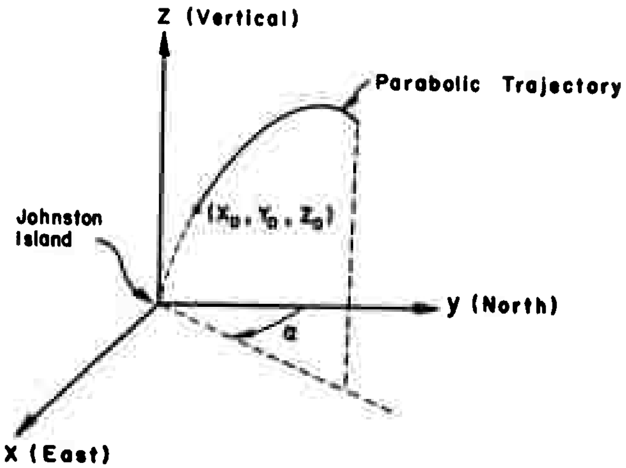


Figure 3.1 Definition of coordinate system.

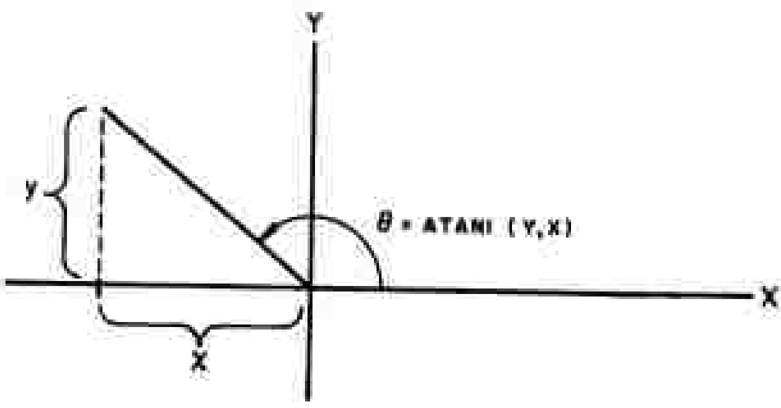


Figure 3.2 Angle θ computation (ATAN1).

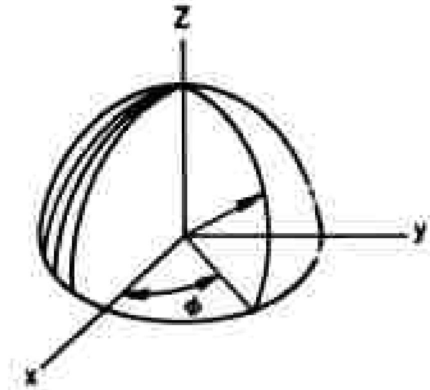


Figure 3.3 Longitude ϕ computation (ATAN1).

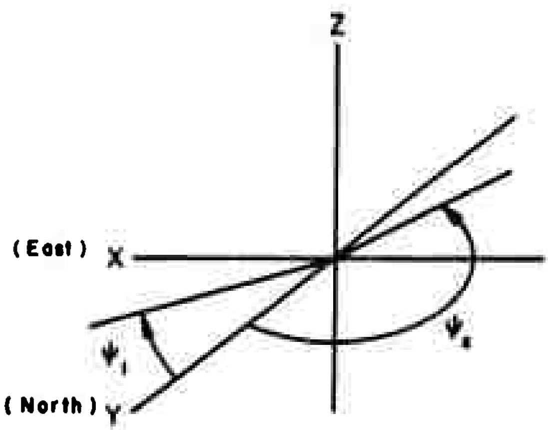


Figure 3.4 X-Y computation (ATAN1).

CHAPTER 4

COMPUTER RESULTS

4.1 OUTPUT FORMAT AND DEFINITIONS

The machine computations and digitalized telemetry data, as output from the computer program, were printed from tapé onto three copy computer printout papers. Three data books for each rocket were required to accommodate all of the data items. Samples of the printout format are included in Tables 4.1 through 4.3. The format was constructed with title headings for each column of data to facilitate easy data analysis. Time in H-time is printed on the lead column in each book in seconds, to the nearest tenth of a millisecond. The data interval is approximately 11 milliseconds.

The telemetry data and computed data from Books 1 through 3 (Tables 4.1 through 4.3), reading from left to right, are interpreted as follows:

a. Payload position in Johnston Island coordinates: X, Y, and Z in kilometers, as defined in the earlier discussions, are the east, north, and vertical displacements in a Cartesian coordinate system based on the geographical location of Johnston Island (Table 4.1).

b. Altitude in kilometers is the vertical distance to the earth's surface.

c. Detector outputs: beta, total gamma, and photometer are the unconverted telemetry data from each detector.

d. Magnetometer readings X_m, Y_m, Z_m are given in gauss units as taken from the digitalized telemetry data.

e. AGC is the automatic gain control given in microvolts for Rockets 8 and 9 and decibels below a milliwatt for all other rockets. Values above 0.7 microvolt or 110 dbm indicate poor data quality.

f. DIFF is the difference between unity and the sum of two squared quantities. Those quantities are the ratio of the smoothed, gain, and bias adjusted magnetometer value to the maximum magnetometer value, for x and y magnetometers, respectively. The number is an index of angular error involved in the attitude angles. As error increases, the absolute value of the number increases.

g. Gain ratio is the ratio of the maximum x-magnetometer reading divided by the maximum y-magnetometer reading and is computed over a 100-data-point group of digitalized magnetometer values. The number is again an indication of angular error as it differs from unity.

h. CODE indicates a time gap in the digitalized data by bracketing asterisks.

i. A, B, and C (Table 4.2) are classified numbers which are defined in Reference 2.

j. Rocket axis orientation azimuth (degrees) and elevation (degrees) are defined as the angle taken positively from north and positively from horizontal, respectively.

k. Beta detector azimuth (degrees) and elevation (degrees) are the pointing direction of the beta detector, with azimuth taken as the positive angle clockwise from north to 180 degrees and negatively counterclockwise to -180 degrees. The elevation angle is positive above horizontal and negative below horizontal.

l. Orientation angle to the earth's field is given in degrees and is the angle between the beta detector's pointing direction and the earth's field vector.

m. 20-degree gamma scanner orientation gives the 20-degree and 90-degree horizontal and vertical gamma detector pointing directions in azimuth and elevation in degrees. The title is incorrect and should properly be 90-degree gamma scanner

orientation. 20-degree gamma scanner orientation is ±180 degrees from the indicated angles. The angle convention is the same as that of the beta detector.

n. Gamma scanner outputs are the telemetry data in counts per 10 milliseconds (Table 4.3).

o. Detector functional values give the converted (volt to indicated units) value for the beta and omnidirectional gamma detector, in MeV per square centimeter per second, and the photometer outputs in watts per square centimeter per steradian.

p. Theoretical field components in Johnston Island coordinates are the outputs from the MAGNET subroutine rotated into Johnston Island coordinates. FR(1) is the eastern component, FR(2) is the northern component, and FR(3) is the vertical component.

4.2 INPUT DATA DESCRIPTION

The computer printouts for each rocket include an Input Data Sheet which includes all initial conditions, time inputs, start and stop times, trajectory information, and beta detector and omnidirectional gamma detector conversion tables. These sheets are presented in Tables 4.4 through 4.8, as taken from the final printouts. Table 4.7 is not final, since the first attempt to reduce the data for Rocket 19 was unsuccessful; the table represents only the first attempt.

TABLE 4.1 OUTPUT FORMAT, ROCKET 19, BOOK 1

BOOK 1 — OUTPUT FROM ATTITUDE DETERMINATION PROGRAM FOR ROCKET 19 — PAGE 1

H-TIME (SEC)	PAYLOAD POSITION IN J.I. COORDINATES X (KM)	Y (KM)	Z (KM)	ALTITUDE H (KM)	DETECTOR OUTPUTS (VOLTS) BETA	TOTAL GAMMA	PHOTO-METER	MAGNETOMETER READINGS (GAUSS) XM	YM	ZM	AGC (MV)	DIFF	GAIN RATIO	CODE
-14.1473	18.709	-18.709	117.861	117.915	-0.01	-0.03	0.06	0.136	0.375	-0.126	-75.8	0.020	1.025	
-14.1353	18.712	-18.712	117.872	117.926	-0.00	-0.02	0.13	0.189	0.351	-0.125	-74.9	0.014	1.025	
-14.1238	18.714	-18.714	117.883	117.937	-0.01	-0.03	0.07	0.239	0.320	-0.123	-74.4	0.006	1.025	
-14.1123	18.717	-18.717	117.893	117.947	-0.00	-0.02	0.07	0.284	0.281	-0.122	-74.0	-0.003	1.025	
-14.1008	18.719	-18.719	117.904	117.958	-0.01	-0.02	0.06	0.323	0.236	-0.121	-73.7	-0.011	1.025	
-14.0893	18.721	-18.721	117.915	117.969	0.00	-0.01	0.15	0.354	0.186	-0.121	-73.4	-0.018	1.025	
-14.0778	18.724	-18.724	117.925	117.979	-0.01	-0.02	0.06	0.377	0.131	-0.121	-73.2	-0.021	1.025	
-14.0663	18.726	-18.726	117.936	117.990	-0.01	-0.03	0.06	0.392	0.073	-0.121	-72.7	-0.023	1.025	
-14.0548	18.729	-18.729	117.946	118.000	-0.01	-0.02	0.11	0.399	0.014	-0.121	-72.8	-0.025	1.025	
-14.0433	18.731	-18.731	117.957	118.011	-0.00	-0.03	0.07	0.397	-0.045	-0.121	-72.7	-0.024	1.025	
-14.0318	18.733	-18.733	117.967	118.021	-0.01	-0.01	0.26	0.385	-0.103	-0.121	-72.4	-0.018	1.025	
-14.0203	18.736	-18.736	117.978	118.032	0.00	-0.04	0.05	0.365	-0.157	-0.122	-71.8	-0.009	1.025	
-14.0088	18.738	-18.738	117.988	118.042	-0.01	-0.02	0.05	0.337	-0.208	-0.123	-71.6	0.005	1.025	
-13.9973	18.740	-18.740	117.999	118.053	0.02	-0.02	0.15	0.302	-0.255	-0.124	-71.0	0.016	1.025	
-13.9858	18.743	-18.743	118.009	118.063	-0.01	-0.03	0.14	0.261	-0.296	-0.125	-71.0	0.024	1.025	
-13.9743	18.745	-18.745	118.020	118.074	-0.01	-0.03	0.04	0.214	-0.333	-0.126	-70.5	0.028	1.025	
-13.9628	18.748	-18.748	118.030	118.084	-0.01	-0.03	0.23	0.161	-0.363	-0.126	-70.5	0.028	1.025	
-13.9513	18.750	-18.750	118.041	118.095	-0.02	-0.04	0.04	0.104	-0.384	-0.127	-69.9	0.027	1.025	
-13.9393	18.753	-18.753	118.052	118.106	-0.01	-0.03	0.11	0.046	-0.396	-0.127	-69.9	0.028	1.025	
-13.9273	18.755	-18.755	118.063	118.117	-0.01	-0.03	0.04	-0.015	-0.399	-0.128	-69.8	0.022	1.025	
-13.9158	18.757	-18.757	118.073	118.127	-0.02	-0.01	0.06	-0.075	-0.393	-0.129	-69.9	0.017	1.025	
-13.9043	18.760	-18.760	118.084	118.138	-0.01	-0.03	0.04	-0.132	-0.378	-0.131	-69.8	0.012	1.025	
-13.8928	18.762	-18.762	118.094	118.148	-0.01	-0.02	0.09	-0.185	-0.355	-0.131	-70.3	0.007	1.025	
-13.8813	18.765	-18.765	118.105	118.159	-0.01	-0.02	0.07	-0.233	-0.325	-0.132	-70.6	0.003	1.025	
-13.8698	18.767	-18.767	118.115	118.169	-0.02	-0.03	0.07	-0.276	-0.287	-0.132	-70.9	0.007	1.025	
-13.8583	18.769	-18.769	118.126	118.180	0.00	-0.02	0.06	-0.314	-0.243	-0.133	-71.3	0.003	1.025	
-13.8468	18.772	-18.772	118.136	118.190	-0.01	-0.02	0.05	-0.348	-0.179	-0.133	-72.5	0.025	1.025	
-13.8353	18.774	-18.774	118.147	118.201	0.00	-0.02	0.17	-0.374	-0.161	-0.133	-73.0	-0.056	1.025	
-13.8238	18.777	-18.776	118.157	118.211	-0.00	-0.02	0.04	-0.391	-0.126	-0.133	-73.9	-0.081	1.025	
-13.8123	18.779	-18.779	118.168	118.222	-0.00	-0.03	0.14	-0.398	-0.077	-0.133	-75.0	-0.056	1.025	
-13.8008	18.781	-18.781	118.178	118.232	-0.00	-0.03	0.07	-0.396	-0.002	-0.133	-76.2	-0.009	1.025	
-13.7893	18.784	-18.784	118.189	118.243	0.01	-0.02	0.04	-0.385	0.064	-0.133	-77.8	0.022	1.025	
-13.7778	18.786	-18.786	118.199	118.253	-0.00	-0.04	0.06	-0.366	0.106	-0.131	-79.7	0.069	1.025	
-13.7663	18.788	-18.788	118.210	118.264	0.00	-0.03	0.18	-0.339	0.120	-0.129	-82.0	0.174	1.025	
-13.7548	18.791	-18.791	118.220	118.274	-0.01	-0.02	0.05	-0.304	0.167	-0.129	-85.4	0.235	1.025	
-13.7433	18.793	-18.793	118.231	118.285	-0.00	-0.02	0.16	-0.262	0.233	-0.129	-91.0	0.226	1.025	
-13.7318	18.796	-18.796	118.241	118.295	-0.00	-0.02	0.07	-0.216	0.316	-0.129	-95.6	0.088	1.025	
-13.7203	18.798	-18.798	118.251	118.306	-0.01	-0.02	0.10	-0.163	0.371	-0.129	-89.4	-0.015	1.025	
-13.7083	18.800	-18.800	118.262	118.317	-0.01	-0.02	0.05	-0.107	0.380	-0.128	-84.5	0.042	1.025	
-13.6963	18.803	-18.803	118.273	118.328	-0.00	-0.02	0.06	-0.049	0.394	-0.126	-82.0	0.032	1.025	
-13.6848	18.805	-18.805	118.284	118.338	-0.00	-0.02	0.15	0.010	0.399	-0.124	-79.1	0.023	1.025	
-13.6733	18.808	-18.808	118.294	118.349	-0.00	-0.01	0.08	0.067	0.394	-0.124	-77.3	0.019	1.025	
-13.6618	18.810	-18.810	118.305	118.359	-0.01	-0.02	0.10	0.122	0.380	-0.123	-76.0	0.018	1.025	
-13.6503	18.813	-18.813	118.315	118.370	-0.01	-0.02	0.09	0.176	0.358	-0.121	-75.4	0.014	1.025	
-13.6388	18.815	-18.815	118.326	118.380	0.00	-0.03	0.28	0.227	0.329	-0.121	-74.2	0.007	1.025	
-13.6273	18.817	-18.817	118.336	118.391	-0.00	-0.01	0.05	0.273	0.292	-0.120	-74.1	-0.000	1.025	
-13.6158	18.820	-18.820	118.347	118.401	-0.00	-0.02	0.10	0.314	0.247	-0.120	-73.2	-0.010	1.025	
-13.6043	18.822	-18.822	118.357	118.412	-0.00	-0.02	0.13	0.347	0.198	-0.119	-73.4	-0.015	1.025	
-13.5928	18.824	-18.824	118.368	118.422	0.00	-0.02	0.05	0.372	0.144	-0.119	-73.1	-0.019	1.025	
-13.5813	18.827	-18.827	118.378	118.433	0.00	-0.02	0.16	0.389	0.088	-0.118	-72.8	-0.020	1.025	

TABLE 4.2 OUTPUT FORMAT, ROCKET 19, BOOK 2

BOOK 2 OUTPUT FROM ATTITUDE DETERMINATION PROGRAM FOR ROCKET 19 PAGE 1

H-TIME	A	B	C	ROCKET AXIS ORIENTATION AZIM.	ROCKET AXIS ORIENTATION ELEV.	BETA DETECTOR ORIENTATION AZIM.	BETA DETECTOR ORIENTATION ELEV.	ANGLE TO EARTH FIELD	20 DEG. GAMMA SCANNER ORIENTATION VERTICAL AZIM.	VERTICAL ELEV.	HORIZONTAL AZIM.	HORIZONTAL ELEV.
(SEC)				(DEG)	(DEG)	(DEG)	(DEG)	(DEG)	(DEG)	(DEG)	(DEG)	(DEG)
-14.1473	65.58	34.8	18.7	109.9	71.1	85.1	-17.3	31.5	-2.5	7.5	35.4	-21.1
-14.1353	65.58	34.8	18.7	109.9	71.1	76.4	-16.0	-3.2	-10.7	9.9	27.2	-18.4
-14.1238	65.59	34.8	18.7	109.9	71.1	67.8	-14.3	-7.6	-19.0	12.1	19.2	-15.6
-14.1123	65.59	34.8	18.7	109.8	71.1	59.2	-12.3	-11.0	-27.6	14.2	11.1	-12.9
-14.1008	65.59	34.8	18.7	109.8	71.1	50.9	-10.0	-13.7	-36.2	15.8	3.2	-10.2
-14.0893	65.59	34.8	18.7	109.8	71.1	42.6	-7.6	-15.8	-45.0	17.2	-4.7	-7.6
-14.0778	65.60	34.8	18.7	109.8	71.2	34.4	-4.9	-17.2	-53.9	18.1	-12.7	-5.2
-14.0663	65.60	34.8	18.7	109.8	71.2	26.3	-2.2	-18.1	-63.0	18.7	-20.7	-3.0
-14.0548	65.60	34.8	18.7	109.7	71.2	18.3	0.5	-18.5	-71.9	18.8	-28.6	-1.1
-14.0433	65.61	34.8	18.8	109.7	71.2	10.1	3.2	-18.4	-81.0	18.5	-36.7	0.6
-14.0318	65.61	34.8	18.8	109.7	71.2	2.1	5.9	-17.7	-89.8	17.8	-44.8	1.9
-14.0203	65.61	34.8	18.8	109.7	71.2	-6.0	8.4	-16.5	-98.5	16.7	-52.6	2.9
-14.0088	65.61	34.8	18.8	109.7	71.3	-14.2	10.7	-14.8	-107.1	15.2	-60.9	3.5
-13.9973	65.62	34.8	18.8	109.7	71.3	-22.6	12.8	-12.5	-115.7	13.4	-69.2	3.7
-13.9858	65.62	34.8	18.8	109.6	71.3	-31.1	14.7	-9.5	-124.1	11.3	-77.4	3.6
-13.9743	65.62	34.8	18.8	109.6	71.3	-39.9	16.3	-5.7	-132.5	9.0	-85.7	3.0
-13.9628	65.63	34.8	18.8	109.6	71.3	-49.0	17.5	-0.4	-141.0	6.4	-94.1	2.1
-13.9513	65.63	34.8	18.8	109.6	71.3	-58.1	18.3	48.7	-149.3	3.7	-102.5	0.7
-13.9393	65.63	34.8	18.8	109.6	71.4	-67.2	18.6	73.3	-157.5	1.0	-110.7	-0.9
-13.9273	65.63	34.8	18.8	109.6	71.4	-76.4	18.5	95.3	-165.8	-1.8	-118.8	-2.8
-13.9158	65.64	34.8	18.9	109.5	71.4	-85.6	18.0	118.0	-174.1	-4.5	-127.0	-5.1
-13.9043	65.64	34.8	18.9	109.5	71.4	-94.3	17.1	145.2	177.9	-7.1	-134.8	-7.4
-13.8928	65.64	34.8	18.9	109.5	71.4	-102.9	15.8	-177.4	169.8	-9.4	-142.5	-9.8
-13.8813	65.65	34.9	18.9	109.5	71.4	-111.2	14.3	-173.0	161.8	-11.6	-150.1	-12.4
-13.8698	65.65	34.9	18.9	109.5	71.5	-119.4	12.4	-169.5	153.7	-13.5	-157.9	-14.9
-13.8583	65.65	34.9	18.9	109.5	71.5	-127.7	10.3	-166.8	145.2	-15.2	-165.9	-17.6
-13.8468	65.65	34.9	18.9	109.4	71.5	-137.9	7.3	-164.3	134.3	-16.9	-176.1	-20.9
-13.8353	65.66	34.9	18.9	109.4	71.5	-141.7	6.2	-163.3	130.3	-17.3	-179.9	-22.1
-13.8238	65.66	34.9	18.9	109.4	71.5	-146.8	4.5	-162.4	124.6	-17.9	174.7	-23.6
-13.8123	65.66	34.9	18.9	109.4	71.6	-153.5	2.4	-161.7	117.3	-18.3	167.6	-25.6
-13.8008	65.67	34.9	18.9	109.4	71.6	-163.6	-1.0	-161.5	106.1	-18.4	156.4	-28.2
-13.7893	65.67	34.9	18.9	109.4	71.6	-172.9	-4.1	-162.0	95.8	-17.9	145.8	-30.3
-13.7778	65.67	34.9	19.0	109.4	71.6	-179.3	-6.1	-162.9	88.8	-17.3	138.4	-31.4
-13.7663	65.67	34.9	19.0	109.3	71.6	177.5	-7.0	-163.8	85.4	-16.9	134.7	-31.9
-13.7548	65.68	34.9	19.0	109.3	71.6	168.5	-9.6	-165.6	75.8	-15.5	124.2	-32.8
-13.7433	65.68	34.9	19.0	109.3	71.7	155.8	-12.9	-168.4	62.8	-12.9	109.3	-33.3
-13.7318	65.68	34.9	19.0	109.3	71.7	141.5	-15.6	-173.4	48.9	-9.3	93.1	-32.7
-13.7203	65.69	34.9	19.0	109.3	71.7	130.6	-17.1	173.9	38.7	-6.3	81.1	-31.4
-13.7083	65.69	34.9	19.0	109.3	71.7	122.2	-17.9	133.4	31.0	-3.8	72.2	-30.1
-13.6963	65.69	34.9	19.0	109.2	71.7	113.1	-18.2	108.1	22.8	-1.2	62.9	-28.2
-13.6848	65.69	34.9	19.0	109.2	71.7	104.2	-18.2	86.5	14.7	1.5	54.0	-26.2
-13.6733	65.70	34.9	19.0	109.2	71.8	95.5	-17.7	65.1	6.8	4.1	45.5	-23.9
-13.6618	65.70	34.9	19.0	109.2	71.8	87.0	-16.9	40.0	-1.0	6.5	37.4	-21.6
-13.6503	65.70	34.9	19.1	109.2	71.8	78.4	-15.8	-1.8	-9.1	8.8	29.2	-19.1
-13.6388	65.71	34.9	19.1	109.2	71.8	69.8	-14.2	-6.5	-17.4	11.1	21.1	-16.4
-13.6273	65.71	34.9	19.1	109.2	71.8	61.2	-12.4	-10.2	-25.8	13.1	13.0	-13.8
-13.6158	65.71	34.9	19.1	109.2	71.9	52.6	-10.2	-13.1	-34.6	14.8	4.8	-11.1
-13.6043	65.71	34.9	19.1	109.1	71.9	44.3	-7.9	-15.3	-43.4	16.2	-3.1	-8.6
-13.5928	65.72	34.9	19.1	109.1	71.9	36.1	-5.5	-16.9	-52.2	17.2	-11.0	-6.3
-13.5813	65.72	34.9	19.1	109.1	71.9	28.1	-2.9	-17.9	-61.0	17.8	-18.9	-4.1

TABLE 4.3 OUTPUT FORMAT, ROCKET 19, BOOK 3

BOOK 3 OUTPUT FROM ATTITUDE DETERMINATION PROGRAM FOR ROCKET 19 PAGE 1

H-TIME	GAMMA SCANNER OUTPUTS 90 DEGREE HORIZ	90 DEGREE VERT	20 DEGREE HORIZ	20 DEGREE VERT	DETECTOR FUNCTIONAL VALUES BETA	TOTAL GAMMA	PHOTOMETER	THEORETICAL FIELD COMPONENTS IN J.I. COORDINATES FR(1)	FR(2)	FR(3)
(SEC)	(COUNTS/10 MSEC)				(MEV/CM**2/SEC)		(WATT/CM**2/STER)	(GAUSS)	(GAUSS)	(GAUSS)
-14.1473	0.22	0.00	0.	0.41	2.20E 04	4.00E-02	2.14E-09	0.04190231	0.29575182	-0.12016052
-14.1353	0.64	0.18	0.35	0.99	2.20E 04	4.00E-02	4.55E-09	0.04190204	0.29575051	-0.12015959
-14.1238	0.83	0.28	2.06	0.50	2.20E 04	4.00E-02	2.42E-09	0.04190176	0.29574924	-0.12015874
-14.1123	0.22	0.06	0.	0.14	2.20E 04	4.00E-02	2.58E-09	0.04190150	0.29574799	-0.12015787
-14.1008	2.60	2.14	0.01	0.23	2.20E 04	4.00E-02	2.05E-09	0.04190123	0.29574673	-0.12015696
-14.0893	0.64	0.12	0.35	0.38	2.20E 04	4.00E-02	5.19E-09	0.04190096	0.29574546	-0.12015609
-14.0778	0.22	0.06	0.	0.59	2.20E 04	4.00E-02	2.14E-09	0.04190070	0.29574420	-0.12015522
-14.0663	0.52	0.18	0.01	0.14	2.20E 04	4.00E-02	2.00E-09	0.04190043	0.29574294	-0.12015431
-14.0548	0.	2.38	0.	0.81	2.20E 04	4.00E-02	3.83E-09	0.04190017	0.29574168	-0.12015343
-14.0433	0.	0.18	0.	0.62	2.20E 04	4.00E-02	2.35E-09	0.04189990	0.29574042	-0.12015256
-14.0318	0.	0.67	0.	1.72	2.20E 04	4.00E-02	9.13E-09	0.04189964	0.29573914	-0.12015168
-14.0203	0.	0.37	2.18	0.75	2.20E 04	4.00E-02	1.74E-09	0.04189937	0.29573790	-0.12015079
-14.0088	1.83	0.28	0.35	1.11	2.20E 04	4.00E-02	1.79E-09	0.04189911	0.29573664	-0.12014991
-13.9973	0.22	0.18	0.	0.26	2.20E 04	4.00E-02	5.34E-09	0.04189884	0.29573537	-0.12014904
-13.9858	0.22	0.25	0.11	1.24	2.20E 04	4.00E-02	4.82E-09	0.04189857	0.29573411	-0.12014816
-13.9743	0.80	0.55	0.35	0.14	2.20E 04	4.00E-02	1.53E-09	0.04189830	0.29573286	-0.12014728
-13.9628	0.58	0.03	0.23	0.62	2.20E 04	4.00E-02	8.27E-09	0.04189804	0.29573160	-0.12014640
-13.9513	1.80	2.51	0.35	0.62	2.20E 04	4.00E-02	1.45E-09	0.04189777	0.29573033	-0.12014551
-13.9393	0.55	0.06	0.35	0.62	2.20E 04	4.00E-02	3.89E-09	0.04189750	0.29572901	-0.12014461
-13.9273	0.83	2.14	0.	0.14	2.20E 04	4.00E-02	1.53E-09	0.04189721	0.29572771	-0.12014369
-13.9158	0.15	0.18	0.	0.14	2.20E 04	4.00E-02	2.29E-09	0.04189695	0.29572645	-0.12014282
-13.9043	1.80	0.67	0.84	0.62	2.20E 04	4.00E-02	1.32E-09	0.04189669	0.29572520	-0.12014191
-13.8928	0.22	0.	0.01	0.41	2.20E 04	4.00E-02	3.19E-09	0.04189643	0.29572394	-0.12014104
-13.8813	0.09	0.18	0.	0.14	2.20E 04	4.00E-02	2.32E-09	0.04189615	0.29572265	-0.12014019
-13.8698	0.31	0.55	0.35	0.62	2.20E 04	4.00E-02	2.43E-09	0.04189589	0.29572140	-0.12013929
-13.8583	0.98	0.25	0.35	0.62	2.20E 04	4.00E-02	2.19E-09	0.04189563	0.29572016	-0.12013840
-13.8468	0.67	0.18	0.35	0.14	2.20E 04	4.00E-02	1.83E-09	0.04189536	0.29571890	-0.12013752
-13.8353	0.	2.14	0.11	0.75	2.20E 04	4.00E-02	6.18E-09	0.04189509	0.29571763	-0.12013667
-13.8238	1.22	0.18	0.01	0.62	2.20E 04	4.00E-02	1.44E-09	0.04189483	0.29571638	-0.12013576
-13.8123	1.19	0.18	0.	0.38	2.20E 04	4.00E-02	4.83E-09	0.04189456	0.29571512	-0.12013489
-13.8008	1.65	0.55	0.35	1.11	2.20E 04	4.00E-02	2.53E-09	0.04189429	0.29571386	-0.12013401
-13.7893	0.22	0.34	0.	0.75	2.20E 04	4.00E-02	1.50E-09	0.04189403	0.29571260	-0.12013315
-13.7778	0.06	0.03	0.	0.14	2.20E 04	4.00E-02	2.17E-09	0.04189377	0.29571135	-0.12013225
-13.7663	0.	0.28	0.	0.72	2.20E 04	4.00E-02	6.43E-09	0.04189350	0.29571009	-0.12013137
-13.7548	0.70	0.67	0.11	1.02	2.20E 04	4.00E-02	1.65E-09	0.04189323	0.29570884	-0.12013050
-13.7433	1.44	0.18	0.35	0.38	2.20E 04	4.00E-02	5.72E-09	0.04189297	0.29570757	-0.12012962
-13.7318	0.	0.18	0.	0.14	2.20E 04	4.00E-02	2.52E-09	0.04189271	0.29570632	-0.12012874
-13.7203	0.77	0.70	0.	0.53	2.20E 04	4.00E-02	3.72E-09	0.04189244	0.29570506	-0.12012786
-13.7083	0.00	1.74	0.	0.50	2.20E 04	4.00E-02	1.90E-09	0.04189216	0.29570375	-0.12012693
-13.6963	0.19	0.09	0.	0.38	2.20E 04	4.00E-02	2.05E-09	0.04189189	0.29570245	-0.12012602
-13.6848	0.	0.67	0.	1.14	2.20E 04	4.00E-02	5.26E-09	0.04189162	0.29570118	-0.12012516
-13.6733	0.22	3.03	0.	0.62	2.20E 04	4.00E-02	2.77E-09	0.04189136	0.29569993	-0.12012427
-13.6618	0.22	0.18	0.	0.50	2.20E 04	4.00E-02	3.63E-09	0.04189109	0.29569867	-0.12012339
-13.6503	0.	0.18	0.	0.75	2.20E 04	4.00E-02	3.09E-09	0.04189082	0.29569743	-0.12012252
-13.6388	1.44	0.89	0.35	1.24	2.20E 04	4.00E-02	1.01E-08	0.04189056	0.29569616	-0.12012164
-13.6273	0.19	1.28	0.	0.14	2.20E 04	4.00E-02	1.85E-09	0.04189029	0.29569492	-0.12012076
-13.6158	0.	0.12	0.01	0.59	2.20E 04	4.00E-02	3.60E-09	0.04189003	0.29569366	-0.12011988
-13.6043	0.09	0.28	0.35	0.75	2.20E 04	4.00E-02	4.56E-09	0.04188976	0.29569240	-0.12011901
-13.5928	0.22	0.43	0.	0.44	2.20E 04	4.00E-02	1.87E-09	0.04188950	0.29569114	-0.12011816
-13.5813	0.	0.64	0.	0.62	2.20E 04	4.00E-02	5.62E-09	0.04188923	0.29568988	-0.12011725

TABLE 4.4 INPUT DATA, ROCKET 8

CONTROL PARAMETERS

TSTART = 58.0 SEC	TLA = 9.0E 05 SEC	POTMET = 8.40E-08 WATT/CM**2/STERADIAN/VOLT
TSTOP = 721.0 SEC	TLB = 9.1E 05 SEC	FREQ =0. RAD/SEC
GBIAS = 8.4012E 04 SEC	TA = 110.0000 SEC	PHASE =0. RAD

CONDITIONS FOR ROCKET TRAJECTORY

ALPHA = 26.20000 DEG	TI = 110.0 SEC	RHOI = 58.310 KM	RODOT = 5.4600E-04
FLAT = 16.73425 DEG	RE = 6371.2 KM	RHOVI = 1.6350 KM/SEC	G = 8.2129E-03
FLONG = 169.52819 DEG	ZI = 137.740 KM	ZVI = 2.7770 KM/SEC	

BETA CONVERSION TABLE
(FLUX IN MEV/CM**2/SEC)

VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX
0.10	4.02E 03	0.20	8.14E 03	0.30	1.21E 04	0.40	1.65E 04	0.50	2.09E 04	0.60	2.53E 04
0.70	2.92E 04	0.80	3.41E 04	0.90	3.80E 04	1.00	4.24E 04	1.10	4.62E 04	1.20	5.17E 04
1.30	5.72E 04	1.40	6.16E 04	1.50	6.60E 04	1.60	6.26E 04	1.70	7.92E 04	1.80	8.58E 04
1.90	9.24E 04	2.00	9.90E 04	2.10	1.06E 05	2.20	1.13E 05	2.30	1.21E 05	2.40	1.30E 05
2.50	1.37E 05	2.60	1.48E 05	2.70	1.54E 05	2.80	1.65E 05	2.90	1.76E 05	3.00	1.87E 05
3.10	1.98E 05	3.20	2.09E 05	3.30	2.20E 05	3.40	2.31E 05	3.50	2.48E 05	3.60	2.64E 05
3.70	2.86E 05	3.80	2.92E 05	3.90	3.14E 05	4.00	3.33E 05	4.10	3.52E 05	4.20	3.74E 05
4.30	3.96E 05	4.40	4.18E 05	4.50	4.40E 05	4.60	4.84E 05	4.70	5.06E 05	4.80	5.50E 05
4.90	5.94E 05	5.00	6.60E 05	5.10	0.	5.20	0.	5.30	0.	5.40	0.

GAMMA CONVERSION TABLE
(FLUX IN MEV/CM**2/SEC)

VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX
0.10	2.21E 04	0.15	3.62E 04	0.20	5.18E 04	0.25	6.91E 04	0.30	8.64E 04	0.35	1.07E 05
0.40	1.28E 05	0.50	1.66E 05	0.60	2.05E 05	0.70	2.44E 05	0.80	2.82E 05	0.90	3.20E 05
1.00	3.58E 05	1.10	4.03E 05	1.20	4.48E 05	1.30	4.87E 05	1.40	5.32E 05	1.50	5.77E 05
1.60	6.28E 05	1.70	6.85E 05	1.80	7.36E 05	1.90	8.00E 05	2.00	8.45E 05	2.10	8.96E 05
2.20	5.73E 05	2.30	1.06E 06	2.40	1.10E 06	2.50	1.18E 06	2.60	1.28E 06	2.70	1.34E 06
2.80	1.44E 06	2.90	1.54E 06	3.00	1.60E 06	3.20	1.82E 06	3.40	2.05E 06	3.60	2.30E 06
3.80	2.62E 06	4.00	2.75E 06	4.20	3.33E 06	4.40	3.84E 06	4.60	4.48E 06	4.80	5.25E 06
5.00	6.46E 06	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TABLE 4.5 INPUT DATA, ROCKET 9

CONTROL PAREMETERS

TSTART = -0. SEC	TLA = 9.0E 05 SEC	POTMET = 5.17E-07 WATT/CM**2/STERADIAN/VOLT
TSTOP = -0. SEC	TLB = 9.1E 05 SEC	FREQ =0. RAD/SEC
GBIAS = 8.5209E 04 SEC	TA = 110.0000 SEC	PHASE =0. RAD

CONDITIONS FOR ROCKET TRAJECTORY

ALPHA = 23.50000 DEG	TI = 110.0 SEC	RHOI = 40.710 KM	RODDT = 4.7800E-04
FLAT = 16.73425 DEG	RE = 6371.2 KM	RHOVI = 1.1686 KM/SEC	G = 8.1130E-03
FLONG = 169.52819 DEG	ZI = 140.620 KM	ZVI = 2.9370 KM/SEC	

BETA CONVERSION TABLE
(FLUX IN MEV/CM**2/SEC)

VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX
0.10	1.65E 04	0.20	3.97E 04	0.30	4.29E 04	0.40	5.61E 04	0.50	6.82E 04	0.60	8.47E 04
0.70	9.90E 04	0.80	1.15E 05	0.90	1.32E 05	1.00	1.43E 05	1.10	1.60E 05	1.20	1.76E 05
1.30	1.98E 05	1.40	2.09E 05	1.50	2.31E 05	1.60	2.53E 05	1.70	2.75E 05	1.80	2.97E 05
1.90	3.19E 05	2.00	3.46E 05	2.10	3.74E 05	2.20	3.96E 05	2.30	4.29E 05	2.40	4.62E 05
2.50	4.95E 05	2.60	5.28E 05	2.70	5.72E 05	2.80	6.05E 05	2.90	6.33E 05	3.00	6.93E 05
3.10	7.37E 05	3.20	7.70E 05	3.30	8.14E 05	3.40	8.69E 05	3.50	9.35E 05	3.60	9.68E 05
3.70	1.03E 06	3.80	1.10E 06	3.90	1.19E 06	4.00	1.26E 06	4.10	1.32E 06	4.20	1.43E 06
4.30	1.48E 06	4.40	1.59E 06	4.50	1.70E 06	4.60	1.81E 06	4.70	1.92E 06	4.80	2.09E 06
4.90	2.20E 06	5.00	2.36E 06	5.10	0.	5.20	0.	5.30	0.	5.40	0.

GAMMA CONVERSION TABLE
(FLUX IN MEV/CM**2/SEC)

VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX
0.10	1.28E 05	0.15	1.79E 05	0.20	2.24E 05	0.25	2.68E 05	0.30	3.10E 05	0.35	3.52E 05
0.40	3.90E 05	0.50	4.67E 05	0.60	5.38E 05	0.70	6.08E 05	0.80	6.85E 05	0.90	7.55E 05
1.00	8.19E 05	1.10	8.90E 05	1.20	9.60E 05	1.30	1.03E 06	1.40	1.11E 06	1.50	1.19E 06
1.60	1.27E 06	1.70	1.34E 06	1.80	1.44E 06	1.90	1.51E 06	2.00	1.60E 06	2.10	1.70E 06
2.20	1.79E 06	2.30	1.89E 06	2.40	1.98E 06	2.50	2.08E 06	2.60	2.18E 06	2.70	2.30E 06
2.80	2.43E 06	2.90	2.53E 06	3.00	3.62E 06	3.20	2.88E 06	3.40	3.17E 06	3.60	3.46E 06
3.80	3.81E 06	4.00	4.09E 06	4.20	4.48E 06	4.40	4.99E 06	0.	0.	0.	0.

TABLE 4.6 INPUT DATA, ROCKET 15

CONTROL PAREMETERS

TSTART = 30.0 SEC	TLA = 9.0E 05 SEC	POTMET = 3.53E-09 WATT/CM**2/STERADIAN/VOLT
TSTOP = 300.0 SEC	TLB = 9.1E 05 SEC	FREQ =0. RAD/SEC
GBIAS = 8.8900E 02 SEC	TA = 121.8100 SEC	PHASE =0. RAD

CONDITIONS FOR ROCKET TRAJECTORY

ALPHA = 21.00000 DEG	TI = 40.0 SEC	RHOI = 9.030 KM	RODDT = 0.
FLAT = 16.73425 DEG	RE = 6371.2 KM	RHOVI = 0.4964 KM/SEC	G = 9.4500E-03
FLONG = 169.52819 DEG	ZI = 30.520 KM	ZVI = 1.4190 KM/SEC	

BETA CONVERSION TABLE
(FLUX IN MEV/CM**2/SEC)

VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX
0.10	7.91E 03	0.20	1.87E 04	0.30	3.02E 04	0.40	4.23E 04	0.50	5.50E 04	0.60	6.82E 04
0.70	8.25E 04	0.80	9.90E 04	0.90	1.15E 05	1.00	1.21E 05	1.10	1.54E 05	1.20	1.76E 05
1.30	1.98E 05	1.40	2.16E 05	1.50	2.42E 05	1.60	2.64E 05	1.70	2.97E 05	1.80	3.19E 05
1.90	3.52E 05	2.00	3.85E 05	2.10	4.07E 05	2.20	4.40E 05	2.30	4.73E 05	2.40	5.06E 05
2.50	5.50E 05	2.60	5.83E 05	2.70	6.16E 05	2.80	6.60E 05	2.90	7.05E 05	3.00	7.48E 05
3.10	7.92E 05	3.20	8.36E 05	3.30	8.80E 05	3.40	9.46E 05	3.50	9.90E 05	3.60	1.04E 06
3.70	1.10E 06	3.80	1.15E 06	3.90	1.26E 06	4.00	1.32E 06	4.10	1.38E 06	4.20	1.43E 06
4.30	1.54E 06	4.40	1.60E 06	4.50	1.70E 06	4.60	1.76E 06	4.70	1.87E 06	4.80	1.98E 06
4.90	2.09E 06	5.00	2.20E 06	5.10	0.	5.20	0.	5.30	0.	5.40	0.

GAMMA CONVERSION TABLE
(FLUX IN MEV/CM**2/SEC)

VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX
0.10	1.60E 04	0.15	2.40E 04	0.20	3.20E 04	0.25	4.03E 04	0.30	4.86E 04	0.35	5.63E 04
0.40	6.40E 04	0.50	8.07E 04	0.60	9.73E 04	0.70	1.12E 05	0.80	1.31E 05	0.90	1.51E 05
1.00	1.66E 05	1.10	1.85E 05	1.20	2.05E 05	1.30	2.24E 05	1.40	2.43E 05	1.50	2.66E 05
1.60	2.88E 05	1.70	3.07E 05	1.80	3.33E 05	1.90	3.58E 05	2.00	3.81E 05	2.10	4.03E 05
2.20	4.28E 05	2.30	4.54E 05	2.40	4.80E 05	2.50	5.06E 05	2.60	5.31E 05	2.70	5.57E 05
2.80	5.83E 05	2.90	6.14E 05	3.00	6.40E 05	3.20	7.04E 05	3.40	7.68E 05	3.60	8.32E 05
3.80	9.09E 05	4.00	9.92E 05	4.20	1.07E 06	4.40	1.17E 06	4.60	1.29E 06	4.80	1.41E 06
5.00	1.57E 06	5.20	1.73E 06	5.40	1.92E 06	5.60	2.21E 06	5.80	2.56E 06	0.	0.

TABLE 4.7 INPUT DATA, ROCKET 19

CONTROL PAREMETERS

TSTART = 24.0 SEC	TLA = 1.1E 02 SEC	POTMET = 3.55E-08 WATT/CM**2/STERADIAN/VOLT
TSTOP = 340.0 SEC	TLB = 2.9E 02 SEC	FREQ =1.29187799E 01 RAD/SEC
GBIAS = 7.6864E 03 SEC	TA = 107.6121 SEC	PHASE =3.44658798E 00 RAD

CONDITIONS FOR ROCKET TRAJECTORY

ALPHA = 135.00000 DEG	TI = 35.0 SEC	RHOI = 5.730 KM	RODOT = 0.
FLAT = 16.73425 DEG	RE = 6371.2 KM	RHOVI = 0.2937 KM/SEC	G = 9.4000E-03
FLONG = 169.52819 DEG	ZI = 29.830 KM	ZVI = 1.5790 KM/SEC	

BETA CONVERSION TABLE
(FLUX IN MEV/CM**2/SEC)

VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX
0.10	2.20E 04	0.20	3.74E 04	0.30	5.28E 04	0.40	6.82E 04	0.50	8.36E 04	0.60	1.01E 05
0.70	1.21E 05	0.80	1.43E 05	0.90	1.65E 05	1.00	1.87E 05	1.10	2.14E 05	1.20	2.42E 05
1.30	2.75E 05	1.40	3.08E 05	1.50	3.52E 05	1.60	3.85E 05	1.70	4.18E 05	1.80	4.73E 05
1.90	5.78E 05	2.00	5.83E 05	2.10	6.49E 05	2.20	7.26E 05	2.30	8.14E 05	2.40	9.13E 05
2.50	1.06E 06	2.60	1.21E 06	2.70	1.43E 06	2.80	1.76E 06	2.90	2.20E 06	3.00	2.86E 06
3.10	3.85E 06	3.20	5.50E 06	3.30	7.70E 06	3.40	8.14E 06	3.50	2.20E 07	3.60	3.30E 07
3.70	5.28E 07	3.80	7.70E 07	3.90	1.10E 08	4.00	2.20E 08	4.10	3.30E 08	4.20	6.60E 08

GAMMA CONVERSION TABLE
(FLUX IN MEV/CM**2/SEC)

VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX
0.04	3.64E 04	0.05	6.63E 04	0.06	9.01E 04	0.07	1.12E 05	0.08	1.34E 05	0.09	1.53E 05
0.10	1.77E 05	0.15	2.82E 05	0.20	3.91E 05	0.25	4.97E 05	0.30	6.05E 05	0.35	7.14E 05
0.40	8.33E 05	0.45	9.52E 05	0.50	1.07E 06	0.55	1.21E 06	0.60	1.36E 06	0.65	1.44E 06
0.70	1.67E 06	0.75	1.80E 06	0.80	1.97E 06	0.85	2.14E 06	0.90	2.34E 06	0.95	2.52E 06
1.00	2.72E 06	1.10	3.16E 06	1.20	3.64E 06	1.30	4.15E 06	1.40	4.76E 06	1.50	5.33E 06
1.60	6.05E 06	1.70	6.80E 06	1.80	7.65E 06	1.90	8.50E 06	2.00	9.52E 06	2.10	1.07E 07
2.20	1.19E 07	2.30	1.32E 07	2.40	1.46E 07	2.50	1.63E 07	2.60	1.77E 07	2.70	1.94E 07
2.80	2.14E 07	2.90	2.34E 07	3.00	2.55E 07	3.10	2.78E 07	3.20	3.06E 07	3.30	3.40E 07
3.40	3.91E 07	3.50	4.42E 07	3.60	4.77E 07	3.70	5.27E 07	3.80	5.95E 07	3.90	6.80E 07
4.00	7.65E 07	4.20	1.02E 08	4.40	1.36E 08	4.60	2.18E 08	4.80	3.23E 08	5.00	4.76E 08
5.20	6.80E 08	5.40	1.02E 09	0.	0.	0.	0.	0.	0.	0.	0.

TABLE 4.8 INPUT DATA, ROCKET 26

CONTROL PAREMETERS

TSTART = 28.0 SEC	TLA = 9.0E 05 SEC	POTMET = 1.80E-08 WATT/CM**2/STERADIAN/VOLT
TSTOP = 330.0 SEC	TLB = 9.1E 05 SEC	FREQ =0. RAD/SEC
GBIAS = 8.5860E 03 SEC	TA = 115.0000 SEC	PHASE =0. RAD

CONDITIONS FOR ROCKET TRAJECTORY

ALPHA = 113.500C0 DEG	TI = 35.0 SEC	RHOI = 5.729 KM	RODOT = 0.
FLAT = 16.73425 DEG	RE = 6371.2 KM	RHOVI = 0.2937 KM/SEC	G = 9.4000E-03
FLONG = 169.52819 DEG	ZI = 29.834 KM	ZVI = 1.5790 KM/SEC	

BETA CONVERSION TABLE
(FLUX IN MEV/CM**2/SEC)

VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX
0.10	1.54E 04	0.20	3.08E 04	0.30	4.73E 04	0.40	5.94E 04	0.50	7.04E 04	0.60	8.14E 04
0.70	9.24E 04	0.80	1.03E 05	0.90	1.15E 05	1.00	1.26E 05	1.10	1.37E 05	1.20	1.54E 05
1.30	1.70E 05	1.40	1.87E 05	1.50	2.09E 05	1.60	2.26E 05	1.70	2.42E 05	1.80	2.64E 05
1.90	2.80E 05	2.00	3.03E 05	2.10	3.24E 05	2.20	3.41E 05	2.30	3.68E 05	2.40	3.90E 05
2.50	4.12E 05	2.60	4.40E 05	2.70	4.62E 05	2.80	4.95E 05	2.90	5.50E 05	3.00	6.05E 05
3.10	6.60E 05	3.20	7.26E 05	3.30	7.92E 05	3.40	8.58E 05	3.50	9.35E 05	3.60	1.01E 06
3.70	1.10E 06	3.80	1.21E 06	3.90	1.32E 06	4.00	1.43E 06	4.10	1.54E 06	4.20	1.70E 06
4.30	1.87E 06	4.40	2.04E 06	4.50	2.20E 06	4.60	2.42E 06	4.70	2.75E 06	4.80	3.08E 06
4.90	3.52E 06	5.00	4.18E 06	5.10	0.	5.20	0.	5.30	0.	5.40	0.

GAMMA CONVERSION TABLE
(FLUX IN MEV/CM**2/SEC)

VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX	VOLTS	FLUX
0.40	3.57E 04	0.45	4.15E 04	0.50	4.76E 04	0.55	5.37E 04	0.60	6.02E 04	0.65	6.63E 04
0.70	7.35E 04	0.75	7.99E 04	0.80	8.67E 04	0.85	9.35E 04	0.90	1.02E 05	0.95	1.10E 05
1.00	1.19E 05	1.05	1.29E 05	1.10	1.38E 09	1.15	1.46E 05	1.20	1.56E 05	1.25	1.67E 05
1.30	1.77E 05	1.35	1.87E 05	1.40	1.99E 05	1.45	2.11E 05	1.50	2.21E 05	1.55	2.34E 05
1.60	2.48E 05	1.65	2.62E 05	1.70	2.72E 05	1.75	2.89E 05	1.80	3.02E 05	1.85	3.16E 05
1.90	3.33E 05	1.95	3.47E 05	2.00	3.64E 05	2.10	3.88E 05	2.20	4.32E 05	2.30	4.76E 05
2.40	5.77E 05	2.50	5.95E 05	2.60	6.46E 05	2.70	7.14E 05	2.80	7.82E 05	2.90	8.66E 05
3.00	9.69E 05	3.10	1.07E 06	3.20	1.19E 06	3.30	1.33E 06	3.40	1.50E 06	3.50	1.67E 06
3.60	1.94E 06	3.70	2.18E 06	3.80	2.45E 06	3.90	2.79E 06	4.00	3.23E 06	4.10	3.57E 06
4.20	4.08E 06	4.30	4.42E 06	4.40	5.10E 06	4.50	5.78E 06	4.60	6.80E 06	4.70	8.85E 06
4.80	1.12E 07	4.90	1.97E 07	0.	0.	0.	0.	0.	0.	0.	0.